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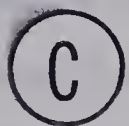
THE UNIVERSITY OF ALBERTA

CONTINUOUS FOAM SEPARATION

OF

ETHYLHEXADECYLDIMETHYLAMMONIUM BROMIDE

BY



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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Continuous Foam Separation of Ethylhexadecyldimethylammonium Bromide" submitted by G.R.K. Shenoy in partial fulfilment of the requirements for the degree of Master of Science in Chemical Engineering.

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ABSTRACT

In spite of the fact that increased attention has been placed on the technique of foam separation during the past few years, adequate quantitative data on the continuous process is not yet available in the literature to facilitate the development of process design methods. Consequently, the real need for much more data necessitates further investigation, in particular of the effect of operating variables on continuous foam separation. Foam separation of ethylhexadecyldimethylammonium-bromide, a cationic surfactant, was investigated in a continuous foam column. The use of this surfactant in previous studies as a potential collector to separate ions from solutions dictated the choice of it in this study.

Liquid residence time, a fundamental variable in the technique of continuous foam separation was investigated in this study. Data concerning the effect of this variable, by varying the liquid feed rate and the volume of the liquid in the column, for columns of diameters 2.0, 2.5, 4.0 and 6.0 inches was obtained, at liquid feed rates of 25, 50 and 75 cc/min. The effect of column diameter with a constant volume of liquid in the columns was established at the above three feed rates. The effect of diffuser pore size and the diffuser size on continuous foam separation was also investigated.

An attempt was made to verify the applicability of the ideal foam model concept to the continuous foam separation of EHDA-Br. It was observed that due to the excessive foam breakage, this concept can not be applied satisfactorily to the present system.

The data obtained from the continuous foam separation of EHDA-Br was analysed using a treatment similar to that of a continuous stirred tank reactor. It was found that the rate of foam separation can be expressed in terms of feed rate, diameter of the column and drain concentration at a constant liquid level of 14.0 inches.

A previously proposed correlation expressing foam ratio in terms of experimental variables was found unsatisfactory for the data obtained during this investigation.

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I. INTRODUCTION

Foam separation, a procedure old in principle but new in application is based on the surface adsorption phenomenon. Certain solutes, due to their surface activity collect at a liquid-gas interface. Foaming simply provides the means for an efficient generation and collection of gas-liquid interfaces. The salient feature of this operational technique is its effectiveness at low concentrations.

This separation method has found application in varied fields. The decontamination of radio-active wastes and treatment of secondary sewage effluents containing non-biodegradable detergents are two industrial applications. Foam separation should become an important process for the separation of certain metallic ions from solutions. This technique is advantageous for the separation of heat sensitive materials.

In spite of the fact that more and more attention has been placed on this technique in recent years, adequate quantitative data is not yet available to develop process design methods. Consequently, there is a real need for much more data, especially regarding the effect of operating variables upon the separation.

The main objective of this work using the Water-Ethylhexadecyldimethylammonium-bromide system are:

(1) to obtain data concerning the effect of operating variables on the performance of a continuous foam separation column, in particular,

(a) the effect of residence time, by varying the feed rate and the volume of liquid in the column for columns of different diameters.

(b) the effect of diffuser size and porosity.

(2) to attempt to formulate a kinetic model describing the foam separation in a continuous foam column.

II. LITERATURE SURVEY

1. Foam Separation as a Laboratory Purification Technique in Chemistry and Biology

Chemists and biologists were the first to show an interest in and utilise the principle of foam separation in the laboratory as a purification technique. Ostwald and Siehr (1) who separated sodium oleates and aluminum stearates, illustrated the biological application of this principle, by concentrating albumin from urine using carbon dioxide. The difference in the surface activities was directly used by Schutz (2) who foamed solutions of sodium cholate and of haemoglobin and serum. Ostwald and Mischke (3) separated 'patent blue' and 'new cocchine' from an aqueous solution of these two dyes. Materials, sensitive to heat have also been separated by this technique. One example was the separation of bacterial spores and vegetative cells from culture medium by Boyles and Lincoln (4). Dubrisay (5) separated riccinic acids from fatty acids while Dubrisay and Taquet (6) separated mixtures of fatty acids by adding a slight excess of sodium hydroxide and blowing nitrogen through the solution. More recently, the effect of pH and concentration upon the foam separation of bovine serum albumin and glucose polymer dextran were investigated by Schnepf and Gaden (7). It was found that at the isoelectric pH one can obtain optimum separation. The separation of escheria coli from a distilled water suspension was investigated recently by Grieves and Wang (8). Shedlovsky (9) describes many applications of this technique in the biological field but a more exhaustive list of studies performed on dyes,

proteins, enzymes and other miscellaneous substances is reported by Rubin and Gaden (10). The importance of all these studies from the chemical engineering point of view is very limited.

2. Foam Separation in Engineering

Foam separation in engineering has been studied both batch-wise and also as a continuous process.

a. Batch Foam Separation

Most of the early investigations in foam separation have been batch-wise and many of the basic studies conducted to date have been batch processes. The industrial applications of foams were first mentioned by Bikerman (11). Since then, the application of this technique to cation extraction has been described by Schnepf et. al., (12) who also tried the extraction of strontium ions using different surfactants. The necessity of purifying effluent waters resulted in the study of the removal of alkyl benzene sulphonate from sewage effluents and early research work in this field was reported by Eldib (13). Recently work has been done on the removal of radio nuclides (14) from large amounts of water. Jacobelly et. al. (15) studied the feasibility of uranium and vanadium recovery by means of foam produced from a quaternary surfactant. They also investigated the separation of uranium from thorium (16) in a hydrochloride medium. The relative effects of the major operating variables such as gas rate, foam height, foam column diameter and concentration were investigated by Kevorkian (17) using Arsket-300. A reliable, recirculating separator was developed by Brunner and Lemlich (18) to study the enrichment with reflux

ratio in the separation of Arsket-300. Grieves et. al. (19) studied the batch foam separation of dodecyl sodium sulphate and alkyl benzene sulphonate using nitrogen. They attempted to develop an equilibrium function from the batch data assuming a single equilibrium contact. The effect of strong inorganic acids and bases on the batch foam separation of EHDA-Br-water system has been investigated by Grieves and Bhattacharyya (20). The effects of pH and phenol and surfactant concentrations were studied by Grieves and Aronica (21), who investigated the foam fractionation of phenol from aqueous solutions using EHDA-Br. Foam fractionation of a positively charged colloid-anionic surfactant system was investigated (22) in 1965 to determine the feasibility of the process for the removal of trivalent iron from water supplies. Since then, EHDA-Br has been used in the foam separations of orthophosphate (23) and colloidal ferric oxide (24). An excellent review of foam separation which includes a description of the apparatus used in early investigations has been reported by Rubin and Gaden (10).

b. Continuous Foam Separation

Many of the recent investigations in the field of foam separation deal with the continuous process. Industrial application demands treatment of substances in large quantities and consequently continuous foam separation may be a feasible technique. The important possible applications are:

- (1) Purification of waste water.
- (2) Removal of surfactants from solutions.
- (3) Removal of ions from solutions by complexing with the surface active materials.

(1) Purification of Waste Water

Pollution of water is caused by contaminants which are usually soluble organic materials, mainly detergents, insecticides, herbicides, phenolic compounds, and other hydrocarbon derivatives. Many of the contaminants are difficult to capture and identify, and they cannot be removed effectively by current treatment methods. Some do not respond to biological attack and they may, therefore, reach drinking water supplies. A logical approach to the removal of dissolved organics which are usually surface active is by the use of foam fractionation.

The application of this technique for the purification of waste waters was first suggested by Eldib (13), who investigated in detail the removal of soluble organics - such as alkyl benzene sulphonate, dyes, and phenol. He also observed that the removal of phenol is difficult due to the fact that the foam produced is very unstable. Since then, work has been performed on the removal of ABS, an anionic surfactant by Rubin and Everett (25), who verified the feasibility of the process for the removal of ABS and other refractory organic compounds, measured by chemical oxygen demand (COD), from the sewage effluents.

Apart from the application of foam separation for the removal of soluble organics from effluent water, this technique has also been used to clarify turbid water (26). Here the addition of a surfactant is essential and Grieves and Schwartz (26) have investigated the effect of pH, air rate, and bentonite clay as a flotation aid, on the clarification of raw water using EHDA-Br.

(2) Removal of Surfactants from Solutions

Surfactants can be naturally separated from solutions by foaming. Considerable amount of work has been performed in this direction and exploratory studies for the removal of isobutyl alcohol were conducted by Kevorkian and Gaden (27). Since then, Harper and Lemlich (28) have investigated the desirability of operating a combined column consisting of a refluxing foam fractionating section situated above a bubble fractionating section. They have reported the range of column operability and the over-all effects of reflux ratio, gas flow rate, and location of feeder on the continuous separation of Triton X-100. Sodium dodecyl sulphate (SDS) has also been studied and Kishimoto (29) reported extensive quantitative results on this surfactant. Grieves et. al. (19) have conducted exploratory studies on continuous foam separation of ABS and SDS. Also Grieves, Crandall, and Wood (30) have compared the separation of three different surfactants, ABS, SDS, and EHDA-Br, and have discussed the operating and design variables affecting the separation. The factors governing the surfactant transfer in a continuous foam column have been studied by Newson (31). Grieves and Wood (32) have studied the effects of foam-solution interface, foam height, column diameter, and liquid solution height on the separation of EHDA-Br from aqueous solutions. They have also investigated the effects (33) of temperature, liquid residence time, and the position of feeder on the separation in a continuous foam separation process. In all of these studies, the surfactants were separated from aqueous solutions.

(3) Removal of Ions from Solutions

Certain ions, present in solutions, can not be directly separated by foaming. An ion, to be separated by foaming should therefore be made surface active and this can be accomplished by complexing the ion using surface active agents. This technique, called 'ion flotation' has a tremendous future and has been receiving increased attention in recent years. The distinction between the two processes, 'ion flotation' and 'foam separation', has not been clearly established. Grieves and Wilson (34) have said, "if the complex formed is insoluble in water and a scum is formed at the solution-froth interface, the process may be considered to be ion flotation. If the complex is soluble and further enrichment is obtained in the foam phase, the process may be considered to be foam separation".

(i) Ion Flotation

Ion flotation should not be confused with froth flotation, an old and well established procedure in mineral ore dressing. Even though the mechanical similarity is inevitable between the two, they are different in principle. Froth flotation deals with a heterogeneous system involving at least two, usually three distinct phases: a liquid and two different solids. Separation is achieved by modifying the particle surface characteristics of one so that it is more readily attached to air bubbles. Hence, froth flotation utilises the artificially magnified density difference, caused by a selective attachment of a solid to gas bubbles.

The most extensive application of this technique has been made in the removal of radio-active cations (35), such as strontium, and caesium from nuclear waste solutions. Since then, studies on uranyl ions (UO_2^{++})

have been performed by Rubin (36). An exhaustive study of ion flotation has been reported in the literature by Sebba (37), who has considered the separation of metals on a group by group basis. This study also deals extensively with the effect of major operating variables, along with the essential characteristics of the collector, the surfactant which is to be added to the solution of metallic ions. Recently, the feasibility of the process of ion flotation of dichromate was studied by Grieves and Wilson (34), where as Grieves and Schwartz (38) investigated the continuous ion flotation of hexavalent chromium, and reported the effects of pH and possible interfering ions, along with the influence of retention time. Also, Grieves and Ettlet (39) have reported on Dissolved air, continuous ion flotation of hexavalent chromium. In all of these studies, EHDA-Br was used as the collector.

III. FOAM SEPARATION THEORY

1. Nature of Foam and Theories of Film Formation

Foam consists of gas bubbles separated by thin liquid films. Although frequently considered as a dispersion of gas in liquid, foam differs from other dispersions of this type because the distances between individual bubbles are small. The structure of foam may vary depending on the number of bubbles coming into contact with each other. But the configuration is stable only when three films come together to form solid angles of 120° each, as shown in Figure 1. Various factors such as concentrations of the system components, temperature, pressure and pH influence the development and stability of foams. In the stable configuration of foam, the junction of three bubbles is of special significance. Plateau was the first to study the essential behavior of foams, hence the junction between three bubbles is called Plateau border (40). The liquid in the film is at a pressure higher than the liquid in the Plateau border. Hence, there exists a pressure gradient from a plane wall to a junction and this pressure gradient causes a kind of suction and plays an important role in foam drainage.

Drainage in foams is due to the movement of liquid caused by the pressure gradient, in addition to the flow due to gravity. Foams may be classified as wet or dry depending on the amount of drainage. A considerable amount of work has been done to study the nature and importance of drainage and to explain it with theoretical models. Drainage acts as internal reflux and gives rise to increased enrichment in the foam phase.

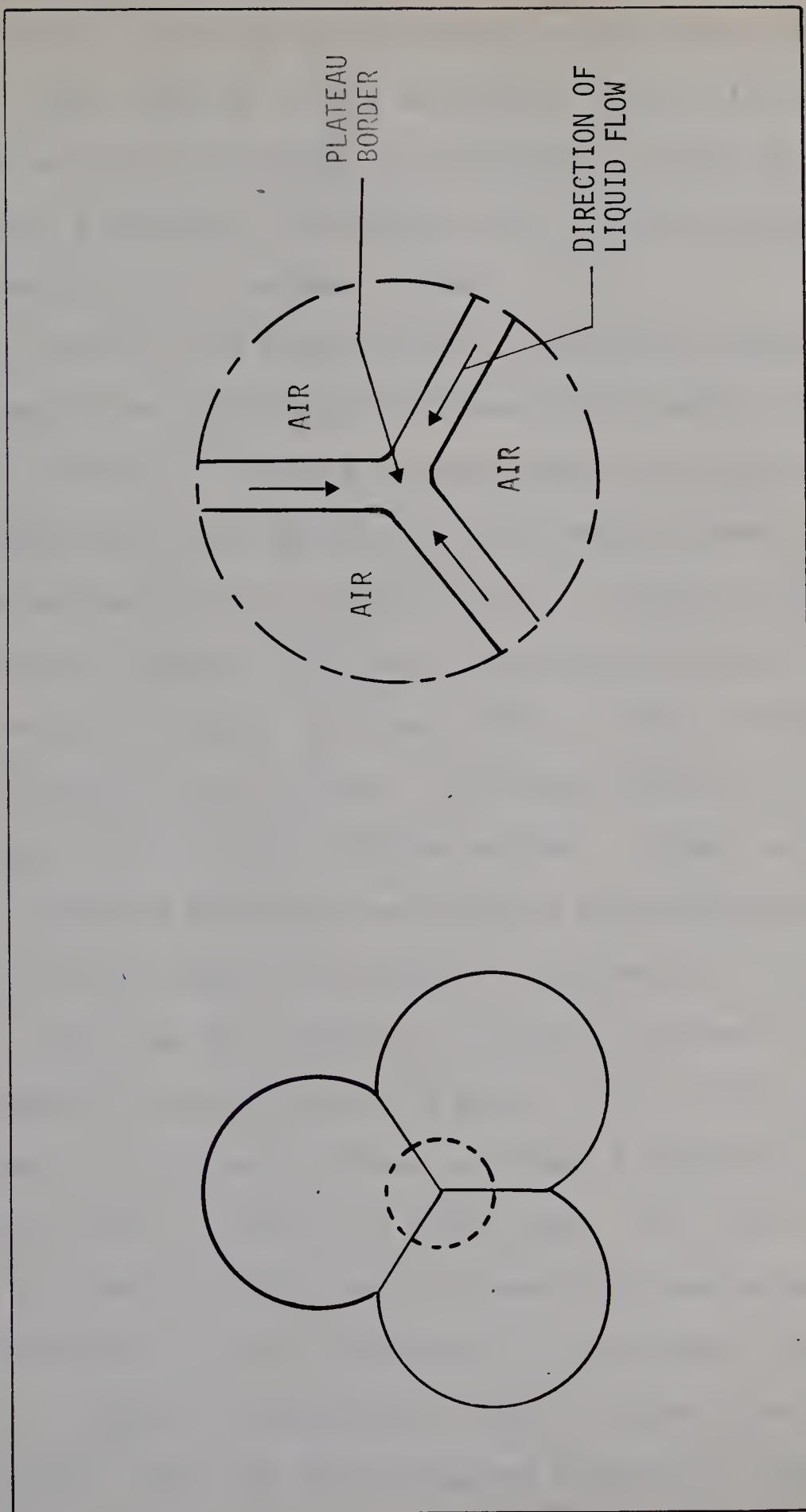


FIG. 1 STABLE CONFIGURATION OF BUBBLES
AND PLATEAU BORDER

Haas and Johnson (41) have reported a model for foam drainage. They have presented equations and theoretical constants to calculate the amount of drainage in foams formed by various substances. Interstitial liquid flow in drainage has been investigated by Leonard (42). Jacobi et. al. (43) have presented a theoretical investigation of foam drainage along with certain correlations for drainage in foams.

Several theories have been proposed to explain the formation of foam. One of the most widely held is the "balanced layer" theory, proposed by Foulk and Miller (44). According to these authors, the liquid films are always formed by the mutual approach of two already existent liquid surfaces. The surface layers of solution resist an attempt to mix them. The resistance arises from the difference in concentration between the surface layer and the bulk solution, since the solute is either positively or negatively adsorbed on the surface. This theory explains the inability of pure liquids and saturated solutions to foam. In these solutions the absence of adsorption eliminates the resisting forces responsible for preventing coalescence, hence the subsequent disappearance of surface. A "cybotatic" theory has been advanced by Hazlehurst and Neville (45) who picture temporarily existing cybotatic groups in the liquid. The surfaces of these groups are constantly eroded to produce disordered liquid while new cybotatic groups are constantly being formed. Any kind of interface provides a permanent base for cybotatic groups which may become stronger and more persistent, possibly approaching the orderliness and stability of crystals. Recently a thermodynamic theory for foam formation was proposed by Nakagaki (46) using foam volume and foam life as criteria.

2. Principles of Foam Separation and Ion Flotation

The tendency of most of the surface-active solutes to collect at the solution-gas interface has been utilised as the basis for foam separation, also known as foam fractionation. This tendency is due to the fact that for thermodynamic stability, the free energy of the surface must be a minimum, and hence, the surface tension must be minimum. This is achieved from the concentration gradient which exists through a very short depth at the surface.

The surface-active agents, called "surfactants", consist of unsymmetrical molecules made up of a hydrophobic group which is organic in nature and a hydrophillic group which has high affinity to water. The migration of the surfactant molecules to the solution-gas interface takes place when the surfactant is dissolved in water or other inorganic solvents. To minimize the contact with the solution, the hydrophobic end of the surfactant molecule tries to orient itself in a particular manner, the result of which is the generation of a surface layer having an excess of surfactant over that contained in the bulk solution. Foaming or bubbling an inert gas through the solution provides an efficient means of generation and collection of the surface layer which is rich in surfactant molecules.

When materials which are not surface-active by themselves, such as metallic ions, are to be separated by foaming, a surfactant should be added to the solution. The surfactant molecule forms a complex with the ion to be separated and this complex is surface-active, and hence can be separated by foaming the solution. This process is termed as "ion flotation", and according to Sebba (37), "it is a fundamental principle in ion flotation

that the final sublimate be insoluble or only slightly soluble in water". This imposes some restriction on the choice of surfactant to be added to the solution which is called the "collector". Though it has been argued that the collector must be of opposite charge to the colligend ion, this sometimes is difficult to determine because of uncertainty about the charge of the colligend ion. This subject and the factors to be considered in selecting a collector for the particular type of process have been discussed in detail by Sebba.

3. Surface Adsorption and Adsorption Isotherms

The essential basis for separation by foaming is surface adsorption. Adsorption may be defined as the concentration of a species at or near phase boundaries. Adsorption can take place at various interfacial combinations of gases, liquids, and solids. Only adsorption at gas-liquid interfaces is of interest in foam separation. The knowledge of all the factors affecting foam separation is very limited and hence, only a few specific and quantitative statements can be made which deal with surface adsorption.

The most general and popular relationship available for the quantitative description of the adsorption at gas-liquid interfaces is Gibbs' equation (47). This equation relates the change in interfacial tension at the boundary between two immiscible phases to the extent of adsorption at the interface. Although the Gibbs' equation is postulated for static systems, it does serve as a basis for predicting enrichments in the foam. Langmuir (48) treated adsorption in a monomolecular form from the standpoint of the dynamic equilibrium between molecules striking the surface and those moving out of the surface after a lapse of time. Using this

concept, he formulated equations for the surface excess. These equations are applicable only to concentrations below the critical micelle concentration and they may not apply well to electrolyte solutions (49). After measuring the surface tensions of aqueous solutions of low molecular weight carboxylic acids and monohydric alcohols, Szyskowski (50) proposed an empirical relationship for the surface excess. Butler and his co-workers (51, 52), showed how Szyskowski's empirical relationship can be arrived at by combining the Langmuir and Gibbs' equations. Other adsorption isotherms are also available and for details regarding these isotherms the reader is referred to sources such as, Davies and Rideal (53), Adamson (54), and Bikerman (40). Since the surface adsorption is the fundamental factor in determining the feasibility of foam separation process, the adsorption isotherms of Gibbs and Langmuir will be reviewed here.

a. Gibbs' Equation for Surface Adsorption

The amount of adsorption of each species at the surface with the change in surface tension of a solution which is in complete thermodynamic equilibrium is given by Gibbs' adsorption isotherm. The condition for such equilibrium is such that the chemical potentials of the various components in the surface layer and the interior of the solution be equal. For constant temperature, the equation is:

$$d\gamma = -\Gamma_1 d\mu_1 - \Gamma_2 d\mu_2 - \dots - \Gamma_i d\mu_i \quad (1)$$

where Γ_i = surface excess of the i th species.
 γ = surface tension of the solution.

μ_i = chemical potential of i th species.

The chemical potential ' μ ' and the activity ' a ' are related by the equation:

$$\mu_i = \mu_i^\circ + RT \ln a_i \quad (2)$$

where μ° = standard chemical potential of the species.

R = universal gas constant.

T = absolute temperature.

Since
$$d\mu_i = (RT/a_i) da_i \quad (3)$$

the equation (1) can be written as

$$d\gamma = -RT \sum \Gamma_i d \ln a_i \quad (4)$$

The importance of the surface excess and the dependency of its numerical value on its definition makes it imperative to define a mathematical interface at some arbitrary position at or near the physical interface. Provided the mathematical interface so defined is planar, the position chosen for it will not invalidate the equation (1).

According to Gibbs' original convention or "Convention 1" of Guggenheim and Adam (55) the mathematical plane is placed so that the "surface excess" of the solvent is zero. Hence, the summation in equation (4) involves only terms for the solute.

b. Langmuir Isotherm

According to Langmuir there is a dynamic equilibrium existing on the surface between the molecules which are being adsorbed and the molecules which leave the surface after some time lapse. Considering the case of a binary solution - one solvent and one solute - it is assumed that the rate at which solute molecules enter the surface layer is proportional to the unoccupied fraction of surface and to the activity of the solute in the surrounding phase. Similarly, the rate at which the solute molecules leave the surface is proportional to the fraction occupied. The equilibrium condition is described by:

$$A_B v_B = k a_B / (1 + k a_B) \quad (5)$$

where v_B = number of solute molecules in surface layer.
 A_B = surface area of each of the solute molecules.
 a_B = activity of the solute.
 k = constant.

In dilute solutions v_B may be taken as equal to Gibbs' surface excess.

Then

$$\Gamma_B = k_1 k a_B / (1 + k a_B) \quad (6)$$

where $k_1 = \frac{1}{A_B}$

Solutions with more than one solute can be treated using the same type of argument.

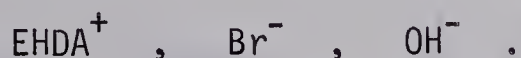
c. Application of Gibbs' Equation to Water - EHDA-Br System

If the solution is ideal or sufficiently dilute, activity can be replaced by the concentration. Hence, for dilute solutions equation (4) may be written as

$$d\gamma = -RT \sum \Gamma_i d \ln x_i \quad (7)$$

where x_i = concentration of i th species.

Brady and Brown (56), Cockbain and McMullen (57) have considered the univalent surfactant to be a completely dissociated electrolyte. Thus, in the interfacial layer of the system EHDA-Br - Water the following species can be said to exist: EHDA-Br and EHDA-OH as a result of the hydrolysis of the salt. Consequently, the following ions have a possibility of being adsorbed in the monolayer:



Therefore, equation (7) can be applied to EHDA-Br - Water system to obtain equation (8).

$$\begin{aligned} -d\gamma = RT \{ & \Gamma_{\text{EHDA}^+} d \ln x_{\text{EHDA}^+} + \Gamma_{\text{Br}^-} d \ln x_{\text{Br}^-} \\ & + \Gamma_{\text{OH}^-} d \ln x_{\text{OH}^-} \} \end{aligned} \quad (8)$$

Very little is known about the hydrolysis of the salt EHDA-Br. But in dilute solutions, it can be said that the quaternary ammonium salts do not hydrolyse appreciably and the pH of the bulk solution does not change markedly with changes in concentration. Hence, the term $d \ln x_{\text{OH}^-}$ can

be neglected. If the assumption that there is no adsorption of OH^- in the interface holds, for complete dissociation of the electrolyte

$$x_{\text{Br}^-} = x_{\text{EHDA}^+} = x_{\text{EHDA-Br}}.$$

Then, $\Gamma_{\text{OH}^-} = 0$, $\Gamma_{\text{Br}^-} = \Gamma_{\text{EHDA}^+} = \Gamma_{\text{EHDA-Br}}$ and from equation (8) therefore,

$$\Gamma_{\text{EHDA}^+} = \Gamma_{\text{EHDA-Br}} = - \frac{1}{2RT} \frac{d\gamma}{d \ln x_{\text{EHDA-Br}}}. \quad (9)$$

But instead of Br^- if OH^- is preferentially adsorbed, then

$$\Gamma_{\text{Br}^-} = 0, \quad \Gamma_{\text{EHDA}^+} = \Gamma_{\text{EHDA-OH}} \quad \text{and hence,}$$

$$\Gamma_{\text{EHDA}^+} = \Gamma_{\text{EHDA-OH}} = - \frac{1}{RT} \frac{d\gamma}{d \ln x_{\text{EHDA-Br}}} \quad (10)$$

Since very little is known about all the adsorbed species, the application of Gibbs' equation may not be fully justified.

4. Ideal Foam Model

In order to simplify the complicated nature of foam separation, an "ideal foam model" has been developed and used. Even though a number of significant simplifications are essential, these must not be overlooked, since they provide a reasonable explanation under specific conditions.

Basic Concepts:

The following assumptions are employed in the ideal foam model approach:

1. The foam is composed of uniform spherical bubbles of diameter D .
2. The bubbles do not break before the exit of foam from the column. This implies one hundred per cent foam stability and absence of internal reflux.
3. The liquid mechanically entrained by foam is of the same concentration as the bulk liquid.
4. Adsorption at the surface is instantaneous and the system is in equilibrium.

Employing these assumptions the following expression can be stated:

$$y_s = x_B + \Gamma A \quad (11)$$

where y_s = concentration of the surfactant in the surface layer at equilibrium, (g/cm^3) .

x_B = concentration of the surfactant in the bulk solution, (g/cm^3) .

Γ = surface excess of surfactant, (g/cm^2) .

A = interfacial area per unit volume of surface layer, $(\text{cm}^2/\text{cm}^3)$.

If the volume occupied by the liquid is neglected, then the number of bubbles per unit volume of foam is

$$\frac{6}{(\pi D^3)} \cdot$$

Interfacial area per unit volume of foam: $\frac{6\pi D^2}{\pi D^3} = \frac{6}{D}$.

Interfacial area per unit volume of surface layer: $A = \frac{6G}{DS}$

where G = volumetric rate of foam, (cm^3/min).

S = volumetric rate of surface layer, (cm^3/min).

The validity of the assumptions made in the ideal foam model approach have been justified by Tran (58) who has also justified the use of this approach for single equilibrium stage operation.

5. Continuous Foam Separation

The title 'continuous foam separation' signifies that the foam separation process is carried out continuously. In this technique, the solution of surfactant is fed into the column at a constant rate and the gas is bubbled into the liquid continuously through a diffuser. The foam rises in the column which is then withdrawn from the top of the column continuously, while a constant volume of the liquid is maintained in the column by withdrawing liquid from the bottom at a constant rate. In the continuous process, large amounts of liquid can be handled and also the amount of separation can be controlled by varying the rates of feed and product solutions.

a. Variables in Continuous Foam Separation

As for any chemical engineering process, there are a number of variables affecting the separation in a continuous foam separation process. The variables in a continuous foam separation process can be classified as fundamental and compound variables.

(i) Fundamental Variables

1. Flow rates of various streams.
2. Concentrations of various streams.
3. pH of the liquid.
4. Temperature of the liquid.
5. Pressure of gas.
6. Type and size of the gas diffuser.
7. Porosity of the diffuser and pore size distribution.
8. Residence time of the liquid.
9. Foam height in the column.
10. Column diameter.

(ii) Compound Variables

1. Surfactant solubility.
2. Surface tension of the solution.
3. Equilibrium relationships.
4. Kinetics of adsorption.
5. Formation and structure of foams.
6. Stability of foams.
7. Density and flow properties of foams.
8. Drainage in the column.
9. Evaporation of solute or solvent.

The fundamental variables have a direct bearing on the amount of separation that can be obtained in a column. The effects of all these variables therefore must be taken into consideration in the design of a foam column. Even though the compound factors also affect the enrichment

in a foam column, they are partially dependent on the fundamental variables. For example, density, structure, flow properties and drainage of foams are dependent on the rate of gas flow, temperature, pressure and diffuser geometry. Hence, all these variables, compound and fundamental affect the separation in a continuous foam separation column. The degree to which each variables has its effect on the separation for a given set of conditions must be assessed in the study of continuous foam separation.

b. Methods of Characterizing the Process

Three important approaches have been proposed for characterizing the foam separation process. These are:

1. Equilibrium approach.
2. Rate approach.
3. Kinetic approach.

(1) Equilibrium Approach

In a continuous foam separation process under steady state operating conditions, the foam leaving the solution is in equilibrium with the residual liquid stream which is continuously removed from the column. A component material balance for the system may be written as follows:

$$L = F + B \quad (12)$$

$$Lx_L = Fy_F + Bx_B \quad (13)$$

where L , F and B are feed, foamate and bottoms rates respectively

(cm³/min), and x_L , y_F and x_B are the concentrations of surfactant in the feed, foamate and bottom streams respectively as shown in Figure 2.

Also

$$Fy_F = Fx_B + SA\Gamma \quad (14)$$

or

$$Fy_F = Sy_S + (F - S) x_B \quad (15)$$

In equations (14) and (15), the assumptions of the ideal foam model have been assumed to be valid. In addition it is assumed that the liquid pool is well mixed so that the bottoms concentration is the same as that in the liquid pool.

The following equations can be derived from equations (12) to (15) and Gibbs' adsorption isotherm.

$$(y_F - x_B) = \frac{-3}{RTD} \frac{dy}{d \ln x_B} \frac{G}{F} \quad (16)$$

$$(x_L - x_B) = \frac{-3}{RTD} \frac{dy}{d \ln x_B} \frac{G}{L} \quad (17)$$

$$(y_F - x_L) = \frac{-3}{RTD} \frac{dy}{d \ln x_B} \frac{G}{F} \cdot \frac{B}{L} \quad (18)$$

The above equations can be theoretically used to predict the overhead and bottoms concentrations for a given feed concentration (x_L), feed rate (L) and foam rate (G), provided the following information is available:

- Relationships between B, F and D at given x_L , L and gas rate (G').
- Surface tension concentration relationship for the surfactant.

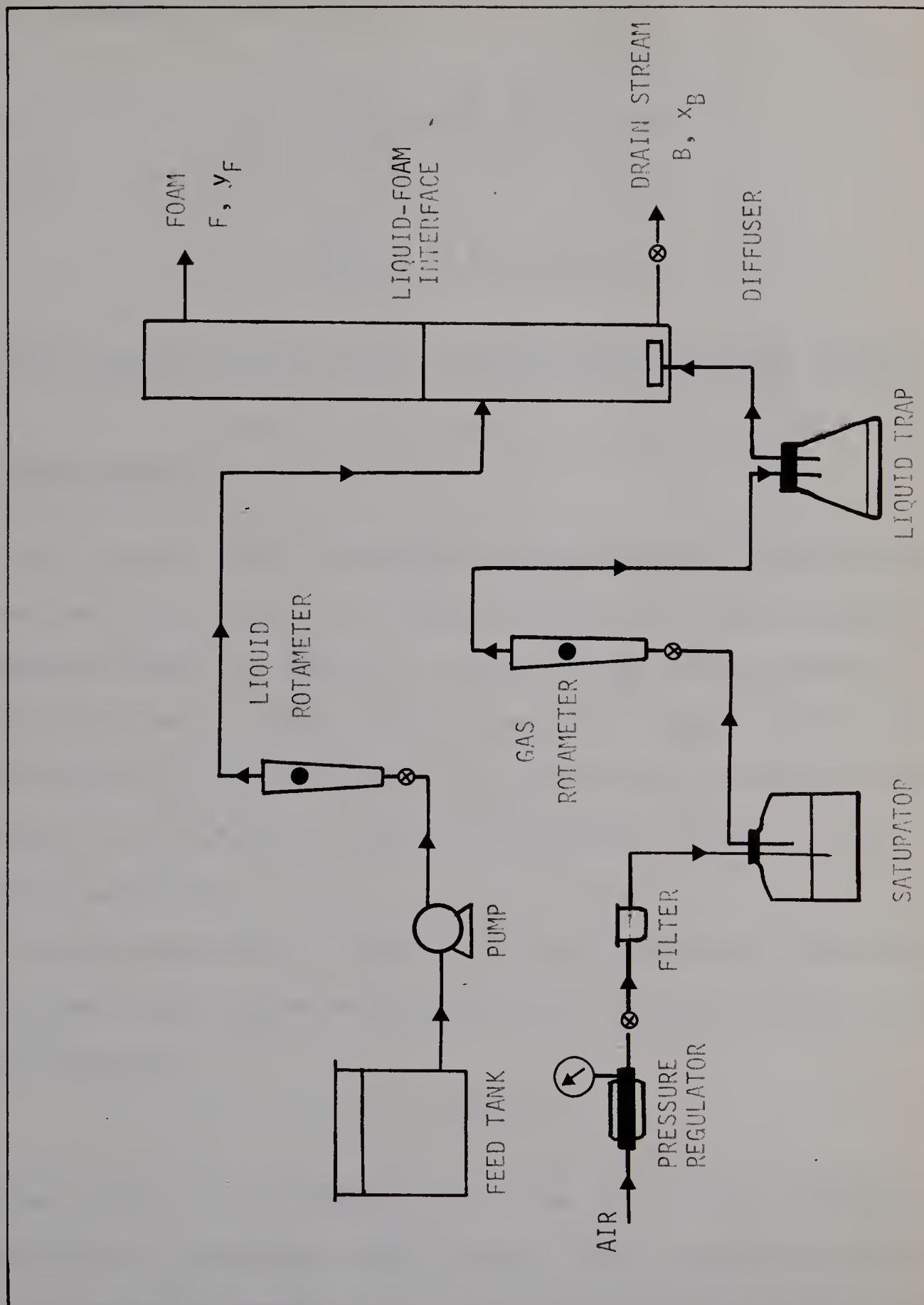


FIG. 2 SCHEMATIC FLOW DIAGRAM OF APPARATUS USED
FOR CONTINUOUS FOAM SEPARATION

Also, the equations for the surface excess can be derived using previous equations (12) to (15).

$$\Gamma_B = \left(\frac{x_L}{x_B} - 1 \right) \frac{L}{G} \frac{D}{6} x_B \quad (19)$$

$$\Gamma_F = \left(\frac{y_F}{x_B} - 1 \right) \frac{F}{G} \frac{D}{6} x_B \quad (20)$$

The above equations may be used for checking the consistency of data.

(2) Rate Approach

Mass transfer in the continuous foam separation can also be explained by the rate concept (19). This approach relates the rate of transfer of a component between two phases to a driving force and a resistance. The difference in concentrations of the transferring component in the two phases from the equilibrium values at the interface, constitutes the driving force. The resistance is generally expressed in terms of a mass transfer coefficient.

In the foam column, the interface is that "separating" the rising and falling liquid streams and the interfacial concentrations may be related by the expression

$$y = y(x) \quad (21)$$

Consider a differential height of foam column dz , with the surfactant concentration in the rising liquid stream y and in the falling liquid stream x . The differential amount of the surfactant transferred between the two streams in the height dz may be written as

$$dN = kr(y_i - y) dA_i = kd(x - x_i) dA_i \quad (22)$$

where y_i and x_i are interfacial concentrations and kd and kr are mass transfer coefficients in falling and rising liquid streams.

The material balance for the differential section dz is

$$dN = d(R'y) = d(D'x) \quad (23)$$

where R' and D' are the rates of rising and falling streams. For steady state operation, assuming that the solution is perfectly mixed, it may be written

$$\begin{aligned} N &= Fy_F = Lx_L - Bx_B = k_d A_i (x_B - x_i) \\ &= k_r A_i (y_i - y_F) \end{aligned} \quad (24)$$

where A_i = interstream area, (cm^2).

N = mass transfer rate, (gm/min).

Equations (22) and (23) can be combined and modified to yield an expression which would permit the calculation of the height of the column necessary to effect a given separation under given operating conditions as follows:

In equation (22), dA_i is defined as

$$dA_i = a' s dz \quad (25)$$

where a' = interstream area per unit volume of foam.

s = cross-section of foam column.

dz = differential height of foam column.

From equation (23)

$$\begin{aligned} dN &= d(R'y) = d(D'x) \\ &= R'dy = D'dx \end{aligned} \quad (26)$$

Substituting these values in equation (22)

$$R'dy = D'dx = kr a'(y_i - y) s dz = kd a'(x - x_i) s dz \quad (27)$$

or

$$Z = \frac{R'}{kr a' s} \int_{y_1}^{y_0} \frac{dy}{(y_i - y)} \quad (28a)$$

$$Z = \frac{D'}{kd a' s} \int_{x_1}^{x_0} \frac{dx}{(x - x_i)} \quad (28b)$$

where Z = height of the foam column.

The above equations (28a) and (28b) will permit the calculation of height of the foam column in terms of falling liquid stream compositions or rising liquid stream compositions.

(3) Kinetic Approach

The third method of explaining the separation in a foam separation process is by the kinetic approach. This concept being a relatively new one has not been applied to continuous foam separation. Rubin et al (59) have tried to explain the ion flotation of soluble copper using this approach on a batch basis.

Assuming that the batch foam separation process can be compared with a batch reactor, the rate equation for the separation can be written as

$$r = \frac{-dC_A}{dt} = kC_A^n \quad (29)$$

where r = rate of separation.

C_A = concentration of species A in the reactor at time t ,
(g mole/litre).

k, n = constants.

The order of the reaction (n), can be determined by obtaining the changes in concentration in the reactor with time. It has been found that the ion flotation of soluble copper follows a first order reversible reaction (59). The constant k can be determined by plotting the concentration versus rate data. Since this concept has just recently been applied to foam separation, the effect of various operating variables on the constants k and n are not known.

A similar approach can be used to explain the operation of a continuous foam separation column by comparing it to a continuous flow stirred tank reactor. The feed enters the reactor continuously and the reaction products are withdrawn from the reactor continuously and in the case of a foam separation column feed is continuously supplied and treated solution withdrawn on a continuous basis. A constant volume of the liquid is maintained all the time in the reactor as in the case of a continuous foam separation column. The concentration of the reactant in the reactor is assumed to be the same as that in the stream withdrawn and in the foam

separation process the concentration of the bottoms is considered to be the same as that in the bulk liquid.

Applying a material balance at steady state to a continuous flow stirred tank reactor results in a rate equation which may be written as

$$r_A = \frac{C_{A0} X_A}{\tau} \quad (30)$$

where r_A = reaction rate, (g mole/lit-min).
 C_{A0} = concentration of the reactant in the feed, (g mole/litre).
 X_A = fractional conversion.
 τ = residence time, (minutes).

As stated it is assumed that the concentration of the surfactant in the bulk stream withdrawn from the column is the same as the concentration of the surfactant in the bulk liquid. It follows that an expression of the same form as equation (30) should be applicable to the foam separation process provided it can be assumed that the surfactant going into the foamate is analogous to the product formed in the reactor due to chemical reaction. Hence, the rate equation for the continuous foam separation becomes

$$r = \left\{ \frac{F \cdot y_F}{\tau L} \right\} \quad (31)$$

Here y_F is expressed in terms of g mole/litre. Knowing the other variables the rate of separation can be determined using the above equation. Since, the gas rate, temperature, bubble size, column diameter etc. affect the separation in a continuous column, these variables also affect the rate of separation or rate of reaction.

Therefore the reaction rate may be represented as a function of these variables.

$$r = \phi(G', T, D_C, D, x_B) \dots \text{etc.}) \quad (32)$$

Since no work has been done based on this approach, it is difficult to obtain the reaction rate as a function of these variables at this time. Hence, there is a significant need for the data on this approach to explain the exact effect of these variables on the rate.

IV. APPARATUS, EXPERIMENTAL PROCEDURE AND RESULTS

1. Apparatus

The schematic flow diagram of the apparatus used in the investigation of continuous foam separation of EHDA-Br - H_2O system is presented in Figure 2. The feed solution, which was stored in a polyethylene tank was pumped into the column continuously at a constant rate as measured by a rotameter. Air, tapped from the main air supply-line was passed through a pressure regulator, a filter and a saturator before being admitted into the column. The line pressure was adjusted to a desired value with the help of the pressure regulator, while to prevent evaporation in the column, the air was saturated with water in the saturator. The filter was used so as to prevent the water in the saturator from reaching the pressure regulator. The saturated air was then passed through a rotameter, where the flow rate was adjusted and measured, after which it was bubbled into the column through a gas sparger or diffuser. A liquid trap was introduced between the sparger and rotameter to prevent liquid from flowing back into the gas line through the diffuser. A foam and a drain stream were withdrawn continuously at the top and the bottom of the column respectively. The rate of withdrawal of the drain stream was adjusted by varying the height of the outlet tube from the bottom of the foam column. In the later experiments a small valve was incorporated in the bottoms line and it was found that it was feasible to adjust the value to regulate the liquid flow from the bottom to maintain a constant liquid level in the column.

In all, four columns with diameters of 2.0, 2.5, 4.0 and 6.0 inches, made of Lucite plastic were used in this study. Except for the study of

the effect of residence time by changing the liquid height in the column, the heights of the columns were six feet. The residence time variation tests, conducted by changing the liquid level in the column, required that the heights of 2.0 and 2.5 inch diameter columns were raised to twelve feet. The foam removal port was located 53.5 inches above the foam-solution interface and the bottoms stream was withdrawn from the port located at the bottom of the column for all tests. The feed ports were located at a height of 10.65 inches above the diffuser in all test except for the variable residence time tests with 2.0 and 2.5 inch columns where the feed ports were located at a height of 43.00 and 27.25 inches above the diffuser respectively.

Diffusers supplied by different companies were used in this study. The details regarding the specifications and source are given in Table IV-1.

To prevent water from evaporating from the surfactant solution, the air stream was saturated with water before being admitted into the column. The air stream was humidified by passing it through a fritted glass tube contained in a bottle filled with distilled water.

All the connections were made of glass and tygon tubing except for the later tests when 1/4 inch copper tubing was used to connect the small valve to the bottom of the column to control the withdrawal of bottoms.

Ethylhexadecyldimethylammonium bromide ($\text{CH}_3 (\text{CH}_2)_{15} (\text{CH}_3)_2 \text{C}_2\text{H}_5\text{NBr}$), a quaternary ammonium salt and a cationic surfactant with a molecular weight of 378.476 was used in this study. This surfactant was supplied by:

Eastman Organic Chemicals
Rochester, New York, U.S.A.
(catalog No. T5661)

TABLE (IV-1)

SPECIFICATIONS OF DIFFUSERS USED IN THE STUDY

THICKNESS OF METAL PLATE (FOR ALL DIFFUSERS) = 1/8 INCH

DESIGNATION	MATERIAL	DIAMETER (INCHES)	PORE SIZE (MICRONS)	SOURCE
D1	Brass	1.25	20 - 25	Dept. of Chem. Eng. Stores, U. of A., Edmonton, Alberta, Canada
D2	Brass	2.50	20 - 25	Same as above
S.S.	Stainless Steel	2.50	20	Pall (Canada) Ltd. Saint-Laurent Montreal 9, Canada
A	Brass	2.50	50 - 130	Pacific Sintered Metals Co. 8333 Hindry Ave., Los Angeles 45, California, U.S.A.
B	Brass	2.50	25 - 50	Same as above
C	Brass	2.50	15 - 25	Same as above
D	Brass	2.50	5 - 15	Same as above

2. Experimental Procedure

a. Operation of the Equipment

For the continuous separation of EHDA-Br, a feed stream containing the surfactant of concentration x_L was fed continuously into the column at a constant rate L measured by a calibrated rotameter. The foam stream of concentration y_F was withdrawn continuously at a rate F from the top of the column while a bulk liquid stream of concentration x_B was also withdrawn continuously at a rate B from the bottom of the column. The air stream was passed through the diffuser continuously at a constant rate G' measured by a calibrated rotameter. The solution-foam interface was maintained at a constant predetermined level above the diffuser with some difficulty by adjusting the rate of withdrawal of the bulk solution from the bottom. Steady state was deemed to exist when all the variables (foam velocity, foamate rate, bottoms rate, foamate concentration and bottoms concentration) became constant with time. Each run was carried out for at least four to six hours to minimize the errors involved with the fluctuations in feed rate and liquid level. Bottoms flow rate was determined volumetrically by collecting the liquid for about 30 to 40 minutes each time. Thus bottoms samples were collected three to five times for each run. These samples along with the foamate samples were analysed to determine the concentration of surfactant in them.

The operating conditions were varied depending on the variable that was being studied. The height of the foam solution interface was maintained at 14.0 inches above the diffuser for all tests except the residence time variation tests. For these latter tests, the liquid levels were calculated

based on the residence times of a 4.0 inch diameter column and at feed rates of 25, 50 and 75 cc/min., in which the liquid level was constantly maintained at 14.0 inches above the diffuser. In addition, tests were conducted in a 2.5 inch diameter column with the solution-foam interface maintained at 8.96 inches above the diffuser. In this particular case, the residence times of the 2.5 inch diameter column were equivalent to the residence times of the 2.0 inch diameter column with a solution-foam interface height of 14.0 inches above the diffuser. The height for the feed port for the 2.0 and 2.5 inch diameter columns were calculated by taking the volume of solution above and below the feed port of 4.0 inch column with a solution-foam interface height of 14.0 inches as the basis. Hence, for tests conducted with the 2.0 and 2.5 inch diameter columns with variation in the liquid height, the amounts of solutions above and below the feed port were equivalent to the amounts of solutions above and below the feed port of the 4.0 inch diameter column.

For residence time variation tests conducted by changing the liquid level, the line air pressure was changed so as to compensate for the increase in the liquid head in the column. The operating conditions for different sets of tests conducted are given in detail in Table IV-2.

b. Determination of Surfactant Concentration

The concentrations of EHDA-Br in the bottoms and foamate were determined by the di-phasic titration method, (60) for the bromide ion with sodium tetraphenyl boron (STPB) solution in chloroform medium. The concentrations were obtained from a calibration curve of STPB consumed versus concentration of EHDA-Br in the solution. This procedure is explained in detail in Appendix B.

Table (IV-2)

Various Operating Conditions Used in the Study

Diameter of the Column (inches)	Liquid Level (inches)	Diffuser	Feed Rate (cc/min)	Line Pressure (psig)	Residence Time (minutes)
2.0	14.00	D1	25.0	4.0	28.84
			50.0		14.42
			75.0		9.61
2.0	56.00	D1	25.0	5.51	115.36
			50.0		57.68
			75.0		38.45
2.5	8.96	D1	25.0	4.0	28.84
			50.0		14.42
			75.0		9.61
2.5	14.00	D1	25.0	4.0	45.06
			50.0		22.53
			75.0		15.02
2.5	36.00	D1	25.0	4.80	115.36
			50.0		57.68
			75.0		38.45
4.0	14.0	D1	25.0	4.0	115.35
			50.0		57.68
			75.0		38.45
4.0	14.00	D2	50.0	4.0	57.68
			75.0		38.45
4.0	14.00	S-S	50.0	4.0	57.68
		A	50.0		57.68
		B	50.0		57.68
		C	50.0		57.68
		D	50.0		57.68
6.0	14.00	D1	50.0	4.0	129.68
			75.0		89.52
6.0	14.00	D2	50.0	4.0	129.68
			75.0		89.52

3. Results

The foamate rate was calculated by the material balance applied to the column at steady state. The concentrations of the surfactant in both the foamate and the bottoms streams were determined by analysis. All analyses were checked by calculating the concentration of surfactant in the foamate by a material balance and comparing it with the concentration determined by the analysis. Tests showing a discrepancy of more than 8.0% were rejected. The results obtained are tabulated in Appendix A.

V. INTERPRETATION OF RESULTS

1. Effect of Operating Variables on Continuous Foam Separation

a. Effect of Residence Time on Continuous Foam Separation

The liquid residence time or simply referred to as residence time can be defined as the time for a unit volume of the feed liquid to pass through the column before it is withdrawn as product. Mathematically, liquid residence time can be defined as

$$\tau = \frac{V_L}{L} \quad (33)$$

where τ = liquid residence time, (minutes).

V_L = volume of liquid in the column, (cm³).

L = rate of feed, (cm³/min).

From equation (33), it is evident that the residence time of the liquid in the column can be varied either by varying the volume of the liquid or by varying only one variable at a time. Residence time is determined by the rate of streams entering and leaving the column. Consequently, it is essential to establish the influence of residence time on the separation efficiency. In spite of the fact that various studies have been carried out to determine the effect of residence time on the separation, its effect is not clearly understood. Grieves and Wood (33) have investigated the effect of this variable on foam separation, both by varying the feed rate and amount of liquid in the column by varying the liquid level using a 4.0 inch diameter column.

In this study, experiments were conducted with 2.0, 2.5, 4.0 and 6.0 inch diameter columns to investigate the effect of liquid residence time on continuous foam separation. The concentration of the surfactant was kept constant throughout the study at 0.150 ± 0.002 g/l, while feed rates of 25, 50 and 75 cc/min were used. Two series of experiments were performed, the first being conducted with a constant liquid level of 14.0 inches above the diffuser in all the columns for the three feed rates. The second series was conducted with changes in the liquid levels in 2.0 and 2.5 inch diameter columns, for the three feed rates mentioned earlier. In the latter series, the 4.0 inch column with a liquid level of 14.0 inches above the diffuser was taken as a reference and the liquid levels for the 2.0 and 2.5 inch columns were based on the residence times of 4.0 inch diameter column for the three different feed rates. An additional set of experiments was conducted with the 2.5 inch column with a liquid level of 8.96 inches above the diffuser, using the three feed rates. In these experiments the residence times of the 2.5 inch column were equivalent to the residence times of 2.0 inch column having a liquid level of 14.0 inches above the diffuser. In all these tests, the foam height above the interface was maintained constant at 53.5 inches.

(i) Effect of Residence Time with Constant Liquid Level and Varying Feed Rate

Some of the results obtained from the first series of experiments conducted with a constant liquid level of 14.0 inches above the diffuser are plotted in Figures 3 to 5, with the gas rate plotted as abscissa and the ratios B/L , x_B/x_L used as ordinates, instead of B and x_B so as to minimize

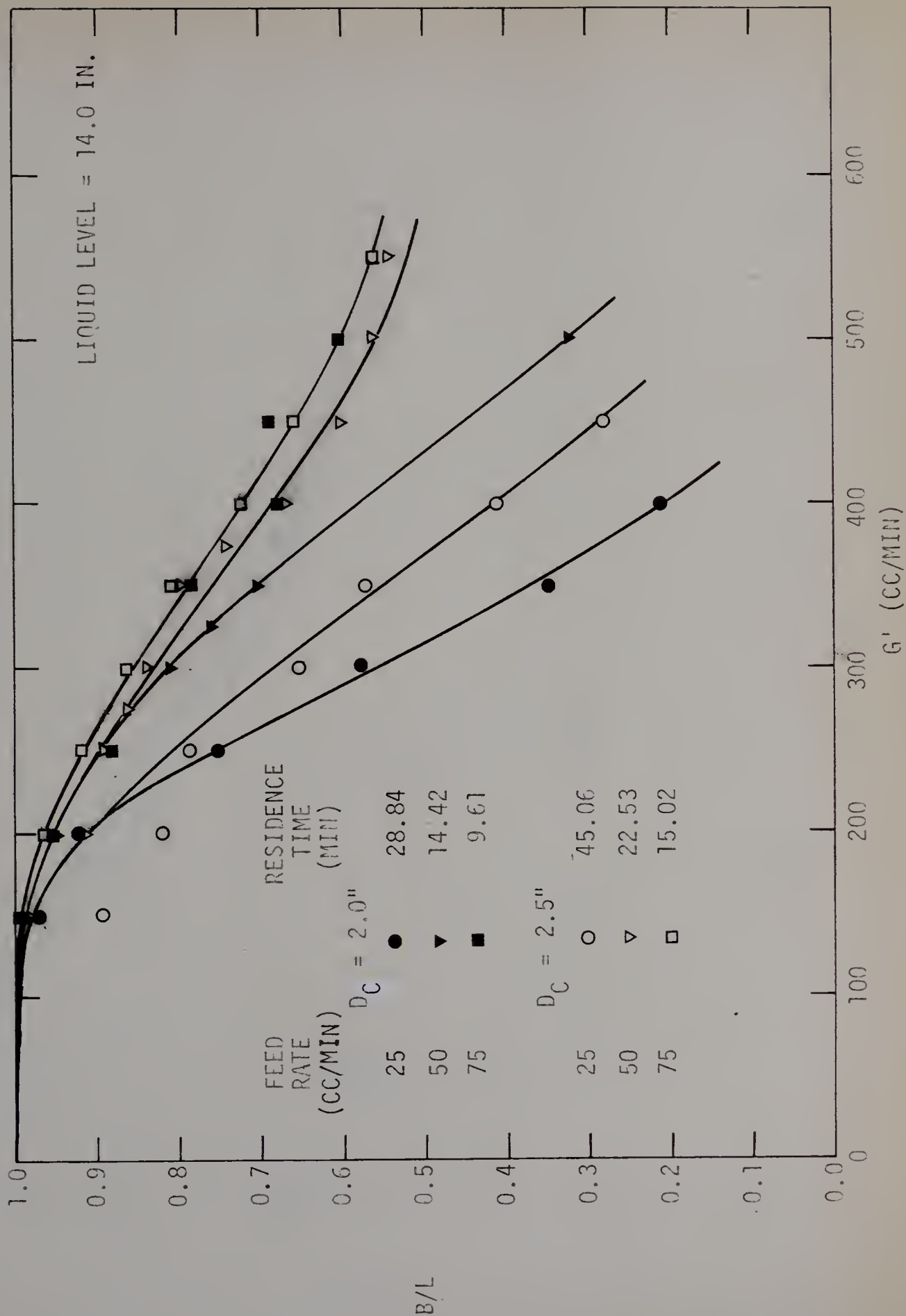


FIG. 3 EFFECT OF RESIDENCE TIME BY VARYING
FEED RATE ON DRAIN RATE

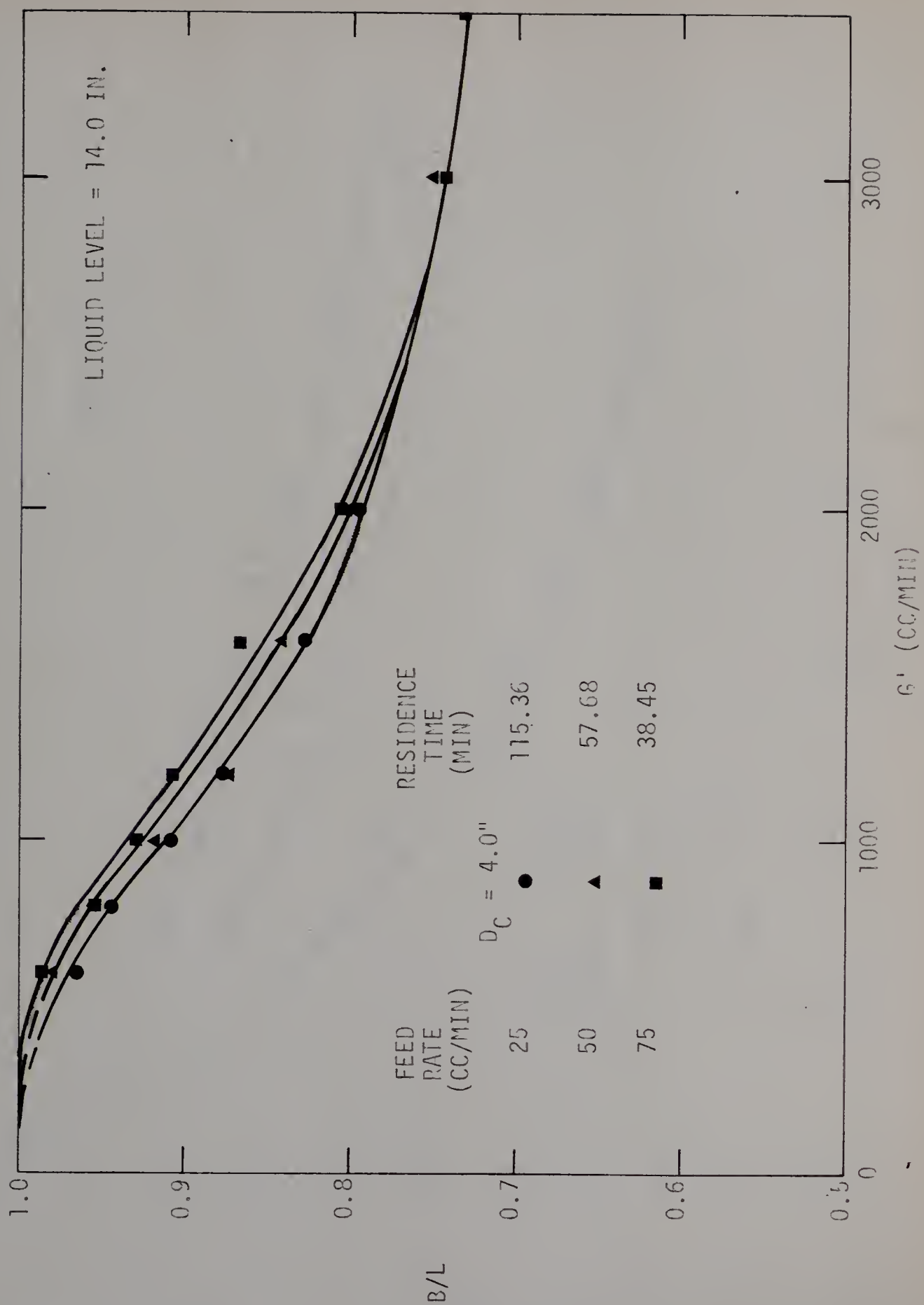


FIG. 4 EFFECT OF RESIDENCE TIME BY VAPYING
FEED RATE ON DRAIN RATE

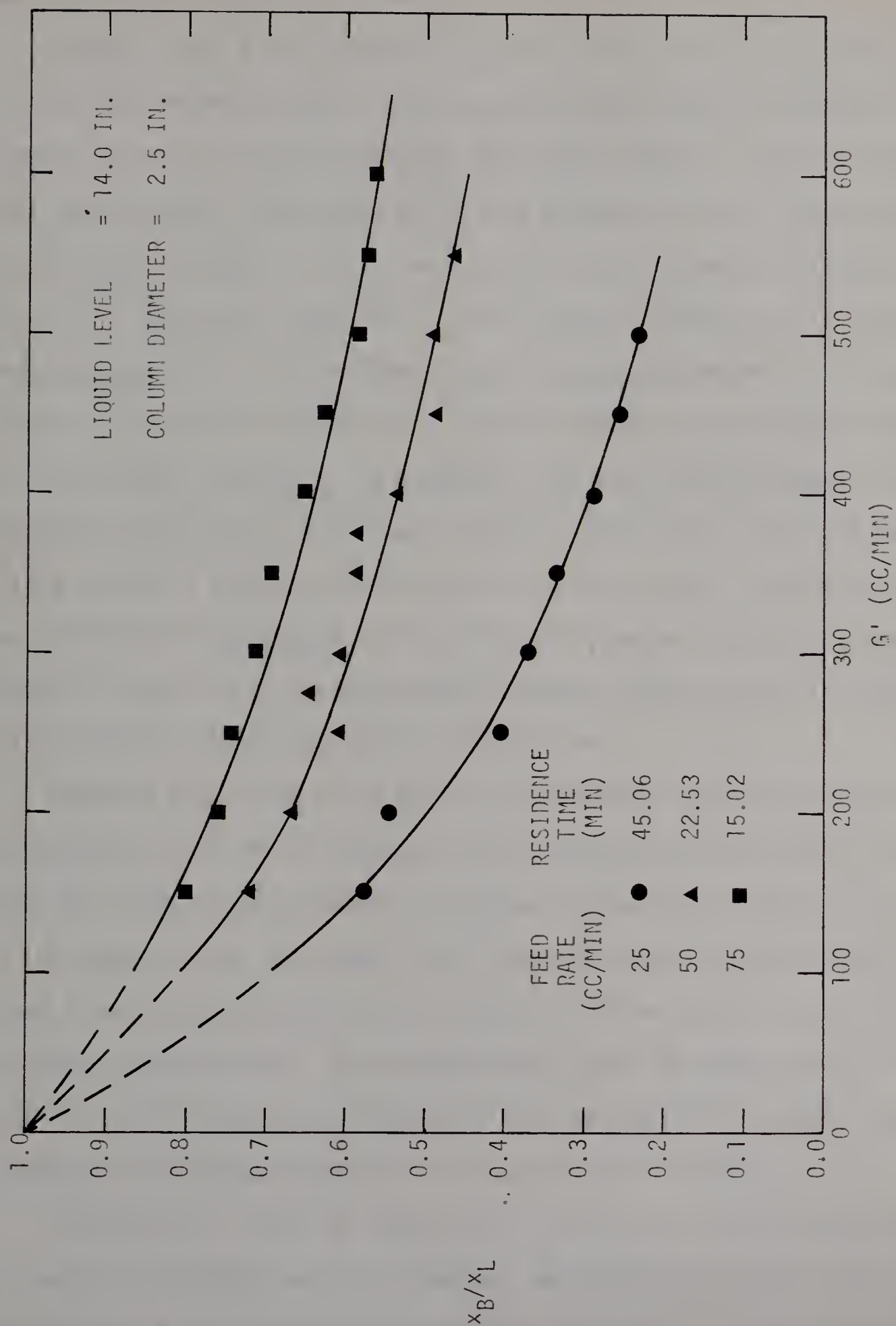


FIG. 5 EFFECT OF RESIDENCE TIME BY VARYING
FEED RATE ON STRIPPING RATIO

the effect of variations in L and x_L .

Figures 3 and 4 show that for a given column, the ratio of drain rate to feed rate decreased with increasing gas rate as would be expected. However, for any gas rate regardless of column diameter, the ratio increases with the increase in feed rate being most prominent in the case of the 2.0 inch diameter column. In the case of the 4.0 inch diameter column, there was only a negligible change in B/L with change in feed rate at low and very high gas rates. As the feed rate is increased keeping the volume of liquid in the column constant, the liquid residence time decreases resulting in a faster movement of an element of the feed liquid through the column. Because of reduction in the time of contact between the liquid and the rising bubbles a smaller amount of bulk liquid per unit volume of feed is carried into the foam phase. The effect of increased feed rate is negligible in the case of larger diameter columns because of the increased drainage due to the larger cross-sectional area.

Figure 5 shows that for a 2.5 inch diameter column the bottoms to feed concentration ratio decreased with increasing gas rate and at any gas rate this ratio increased with an increase in feed rate. As the gas rate is increased for any feed rate, the increased amount of surface area produced allows more surfactant to be removed from the solution decreasing the drain concentration. At a constant gas rate, the amount of gas available for contact with a unit volume of feed decreased as the feed rate is increased and consequently the drain concentration increased.

To study this effect of feed rate on the ratio of drain concentration to feed concentration, a more convenient representation of the data is to plot the ratio of drain to feed concentration versus the ratio of air

rate to feed rate as shown in Figure 6. It was observed that a single curve represented all feed rates and air rates used. This effect indicated that for a given feed concentration, the drain concentration was fixed at a fixed volume of air delivered per unit volume of feed treated. This confirmed the observations of Grieves and Wood (33) who pointed out the analogy between the effect of G'/L upon foam separation and the effect of the quantity of heat per unit weight of feed upon continuous distillation. The results obtained with other columns were similar.

(ii) Effect of Residence Time by Varying Liquid Level and Feed Rate

Experiments were conducted using 2.0 inch and 2.5 inch diameter columns in which both the liquid level and the feed rate were varied. The results for the 2.5 inch diameter column with liquid levels of 8.96, 14.0 and 36.0 inches above the diffuser and feed rates of 25, 50 and 75 cc/min are plotted in Figures 7 and 8. Figure 7, where B/L is plotted versus G' , shows that the ratio of drain rate to feed rate decreased with increasing gas rate. It also shows that at any gas rate and for the feed rates employed the ratio increased with increased liquid level except at the feed rate of 75 cc/min, where no change in the ratio was observed for an increase in the liquid level from 8.96 to 14.0 inches. This probably occurred because of a complete degree of mixing that existed due to the high turbulence.

Figure 8 shows that at any gas rate the overhead concentration was independent of liquid level from 8.96 to 14.0 inches for feed rates of 25, 50 and 75 cc/min. However, when the solution height was increased

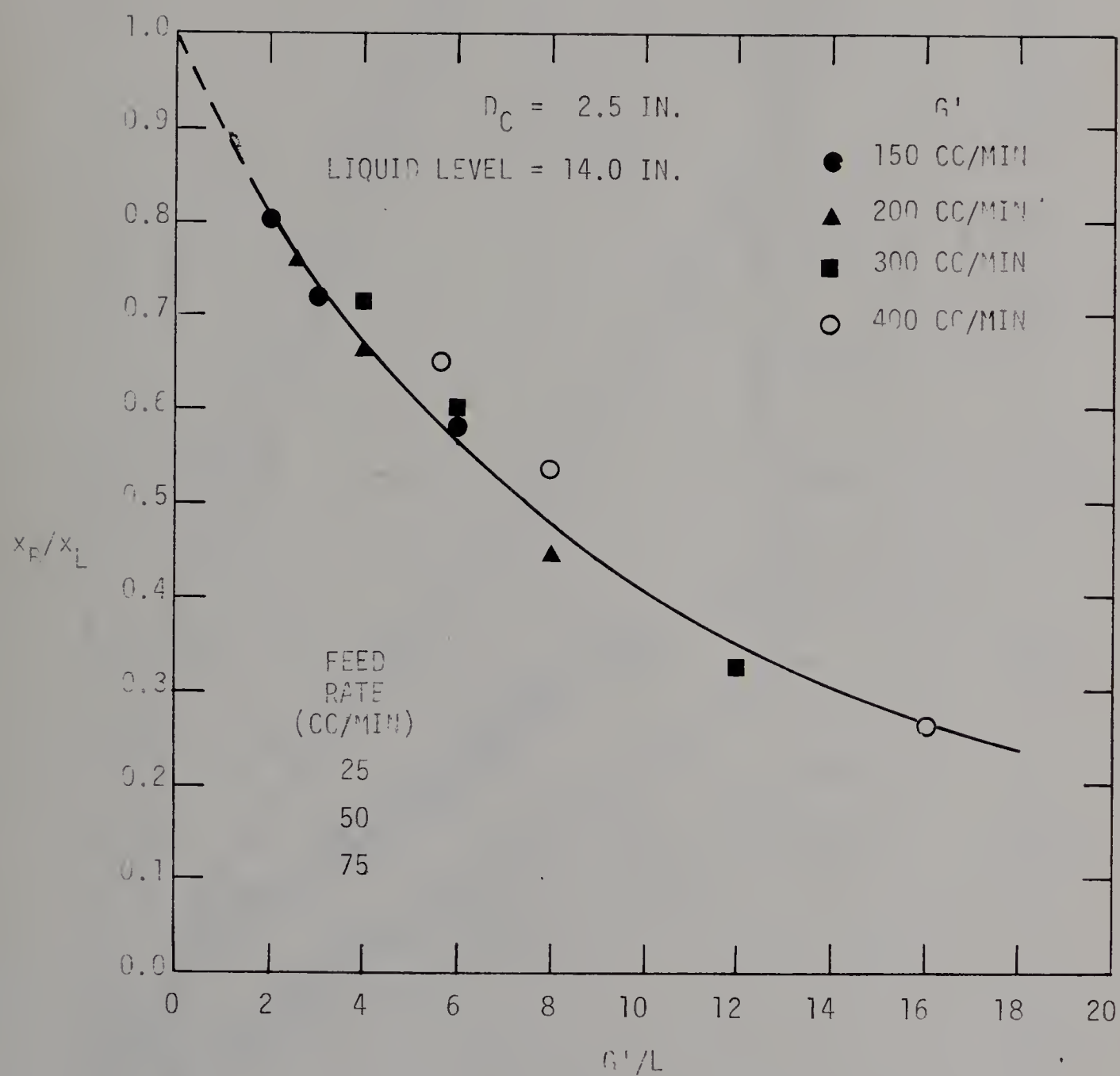


FIG. 6 RELATIONSHIP BETWEEN STRIPPING RATIO AND G'/L FROM VARIABLE FEED RATE EXPERIMENTS

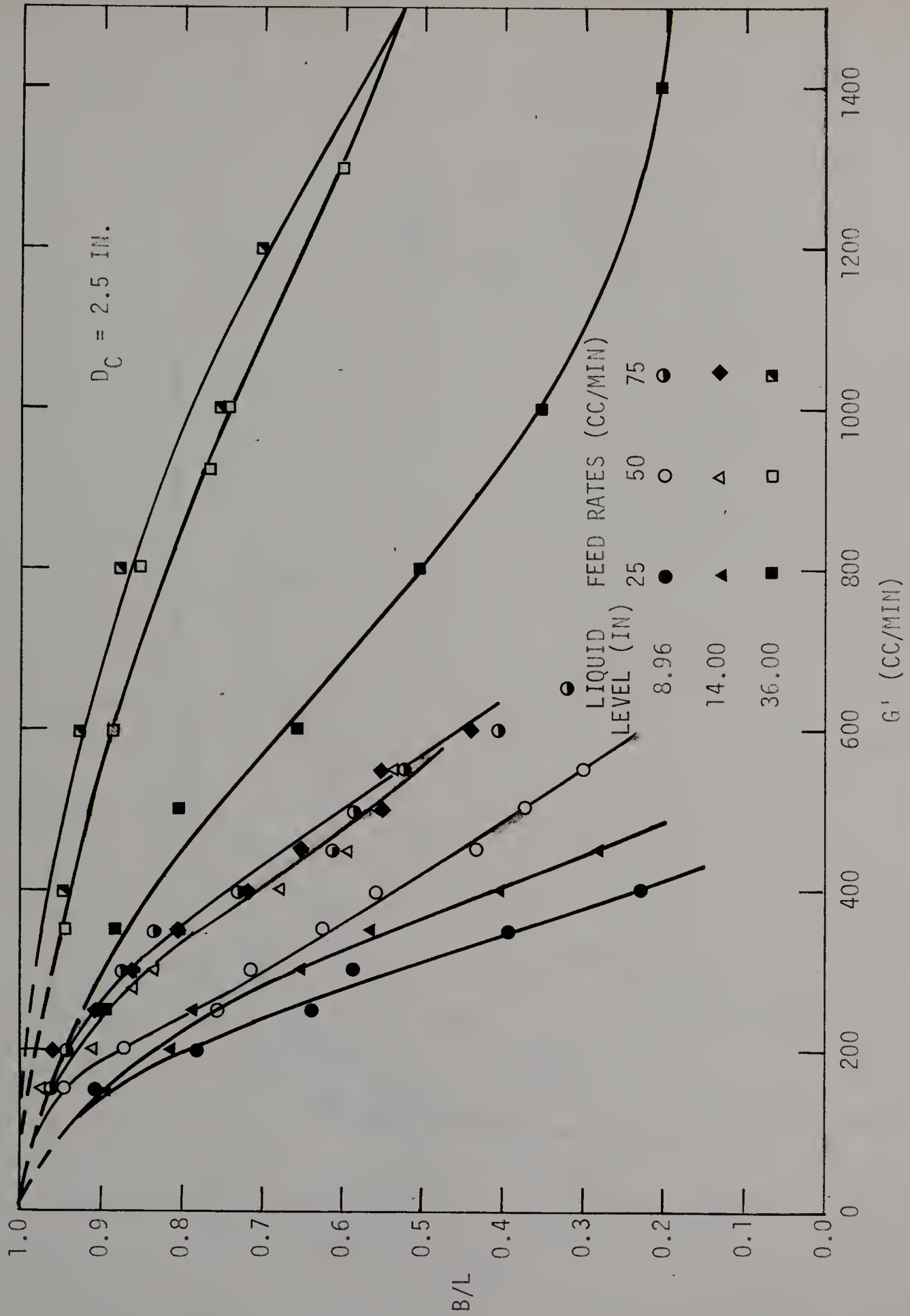


FIG. 7 EFFECT OF RESIDENCE TIME BY VARYING LIQUID LEVEL AND FEED RATE ON DRAIN RATE

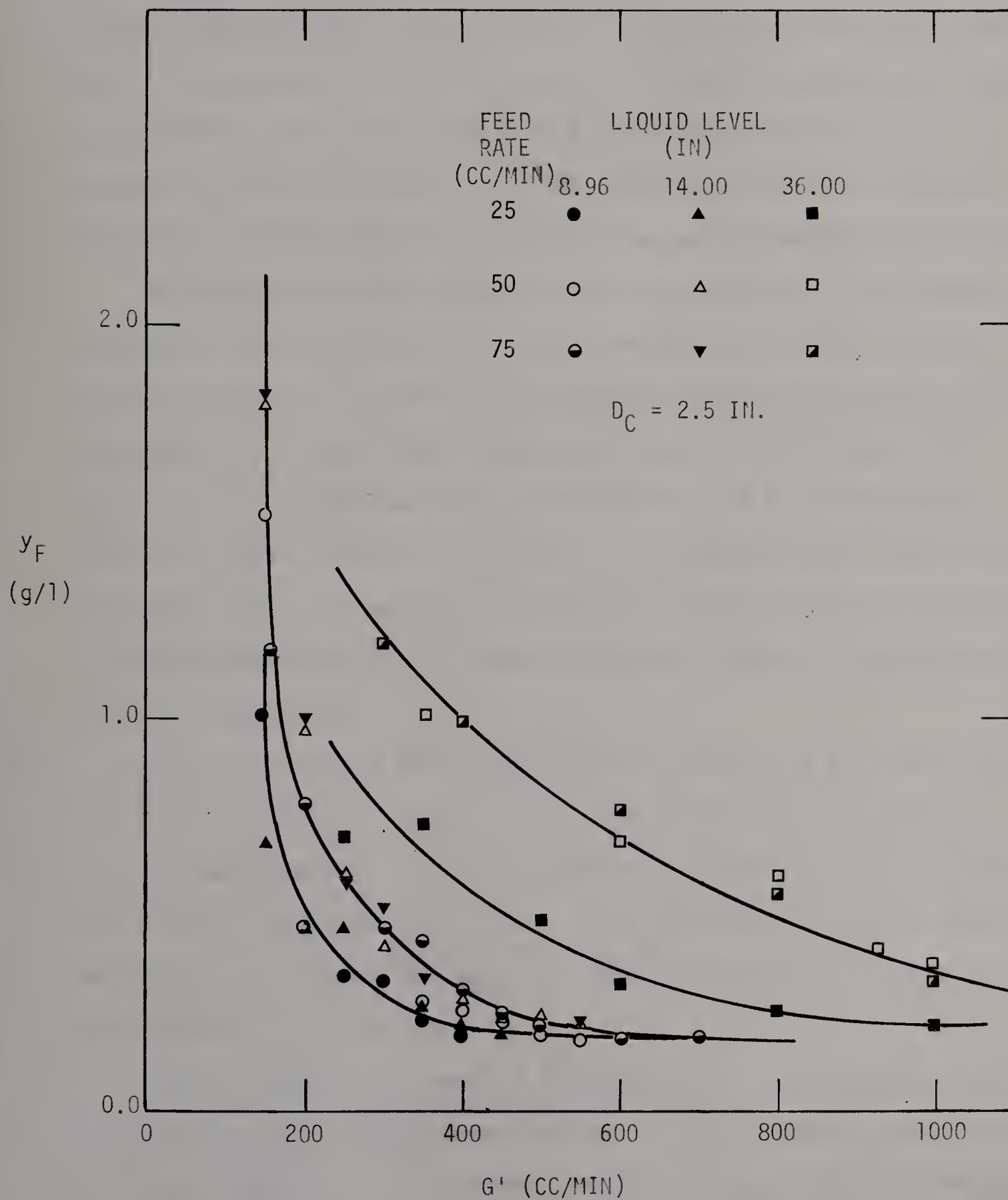


FIG. 8 EFFECT OF RESIDENCE TIME BY VARYING LIQUID LEVEL AND FEED RATE ON OVERHEAD CONCENTRATION

to 36.0 inches at all feed rates, the overhead concentration also registered a sharp increase. This is due to the fact that the residence time for the bubbles has been increased sufficiently by the additional height of solution to allow the excess bulk liquid to be stripped clear. The amount of bulk liquid carried into the foam by these bubbles decreased resulting in a higher overhead concentration and an increased drain rate.

A similar effect was observed in the case of the 2.0 inch diameter column yet the investigation of Grieves and Wood (33) with a 4.0 inch diameter column and different liquid heights showed the separation to be independent of liquid height. They explained this on the basis that equilibrium is rapidly achieved in the solution and a rate approach to the mass transfer process is not valid. The results of this study seem to indicate that the phenomena is one of entrainment and thus the effect of column diameter might have over-shadowed the effect of liquid height in their investigation.

Harper and Lemlich (28) investigated the effects of gas flow rate, reflux ratio and feed location on the separation of Triton X-100 in a 4.8 cm diameter column with an elongated liquid section of 110 cm termed as the bubble fractionating section. They concluded that the incremental advantage of increasing the length of the liquid section was small for the system Triton X-100-water.

Results showing the effect of liquid height on the stripping ratio at feed rates of 25 and 50 cc/min using a 2.5 inch diameter column are plotted in Figure 9. It is evident that the stripping ratio is independent of the liquid solution height at a feed rate of 25 cc/min but at 50 cc/min the stripping ratio decreased with an increase in liquid height

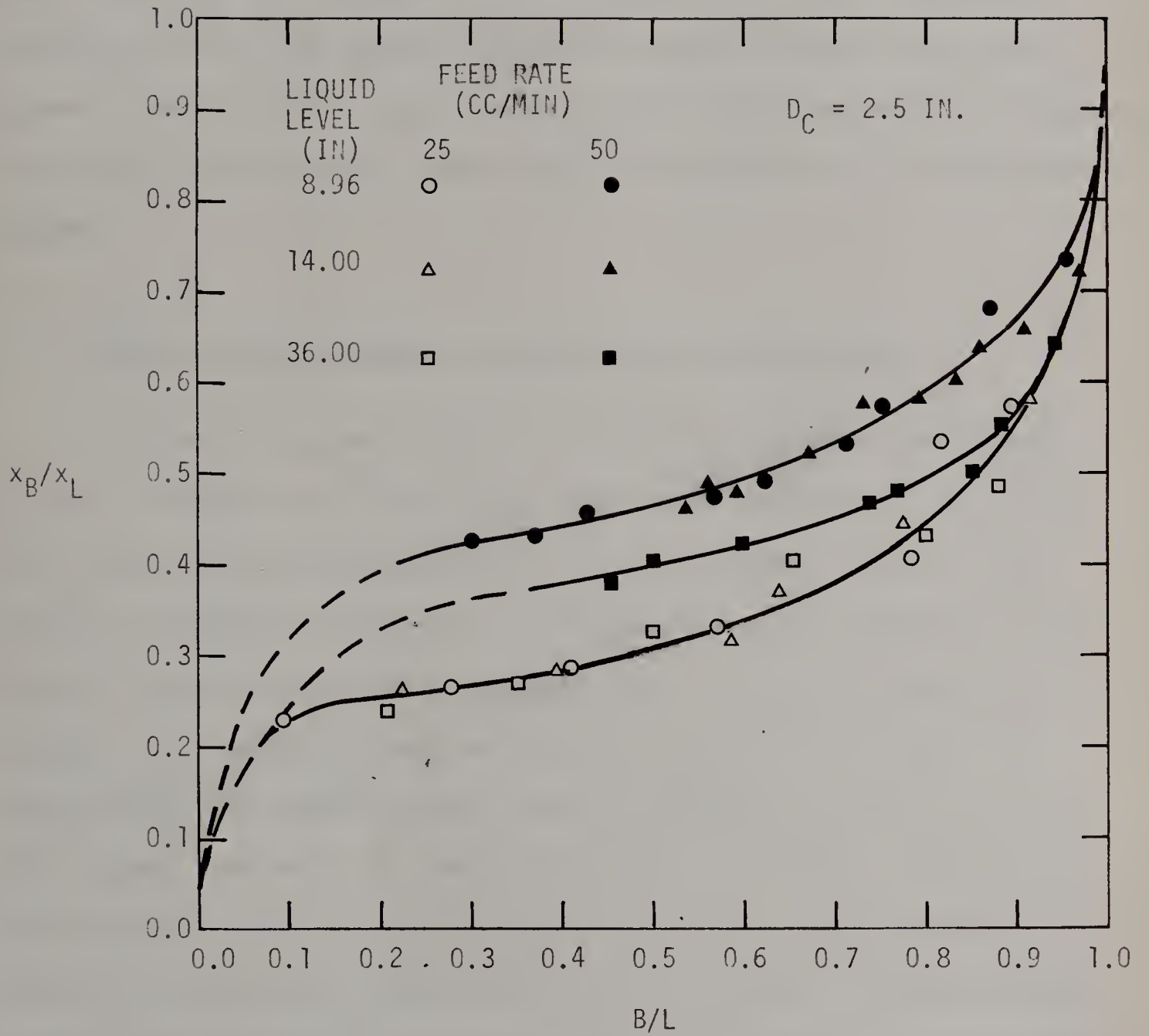


FIG. 9 RELATIONSHIP BETWEEN STRIPPING RATIO AND B/L
FROM VARIABLE LIQUID LEVEL EXPERIMENTS

from 14.0 inches to 36.0 inches. The effect of liquid level was also observed at a feed rate of 75 cc/min. So, it can be concluded that the liquid height has no effect on stripping at low feed rates and only a small effect on the stripping ratio at higher feed rates. Results obtained with a 2.0 inch diameter column for three different feed rates showed a similar effect, which further confirms the observations of Harper and Lemlich (28) who used a feed rate of 32 cc/min with a 4.8 cm diameter column.

b. Effect of Column Diameter on Continuous Foam Separation

The effect of column diameter on separation has been investigated by Tran (58) with a constant liquid level in the columns. In this study this effect was investigated with a constant volume of liquid in the columns of different diameters. Experiments were conducted with 2.0, 2.5 and 4.0 inch diameter columns with 176.0 cubic inches of liquid in the columns. The foam height was maintained constant at 53.5 inches above the solution-foam interface while the liquid heights in 2.0, 2.5 and 4.0 inch columns were 56.0, 36.0 and 14.0 inches respectively. The feed concentration was also constant at 0.150 ± 0.002 g/l. Experiments were conducted with three feed rates of 25, 50 and 75 cc/min. The same diffuser (1.25 in. diameter porous brass plate, 20 - 25 μ pore size) was used for all the columns. Some of the results obtained are plotted in Figures 10 and 11.

Figure 10 shows the ratio of drain to feed rate as the ordinate while the gas rate is plotted as the abscissa for a feed rate of 25 cc/min. The ratio B/L decreased with increasing gas rate and the rate of decrease of

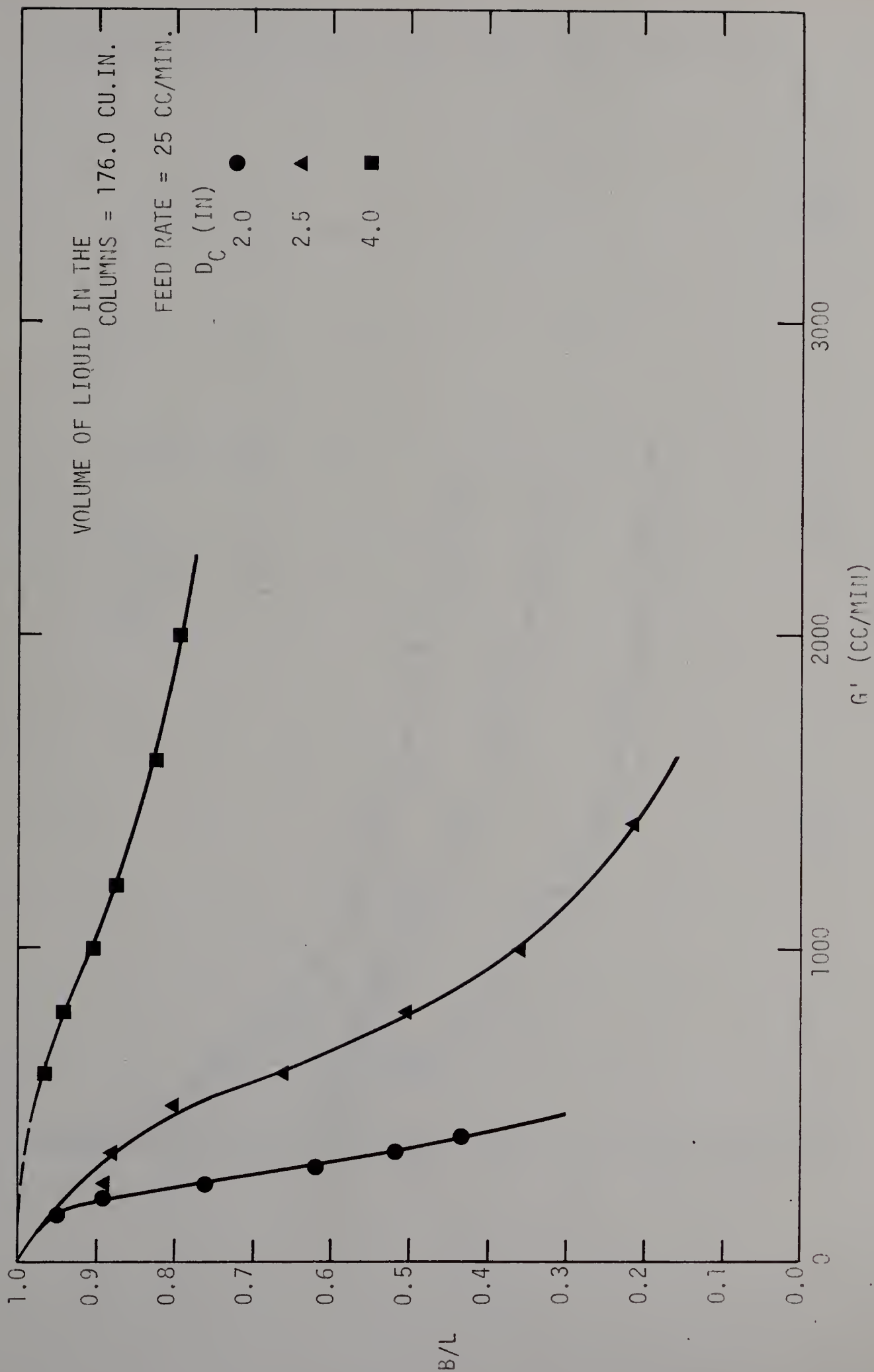


FIG. 10 EFFECT OF COLUMN DIAMETER ON DRAIN RATE

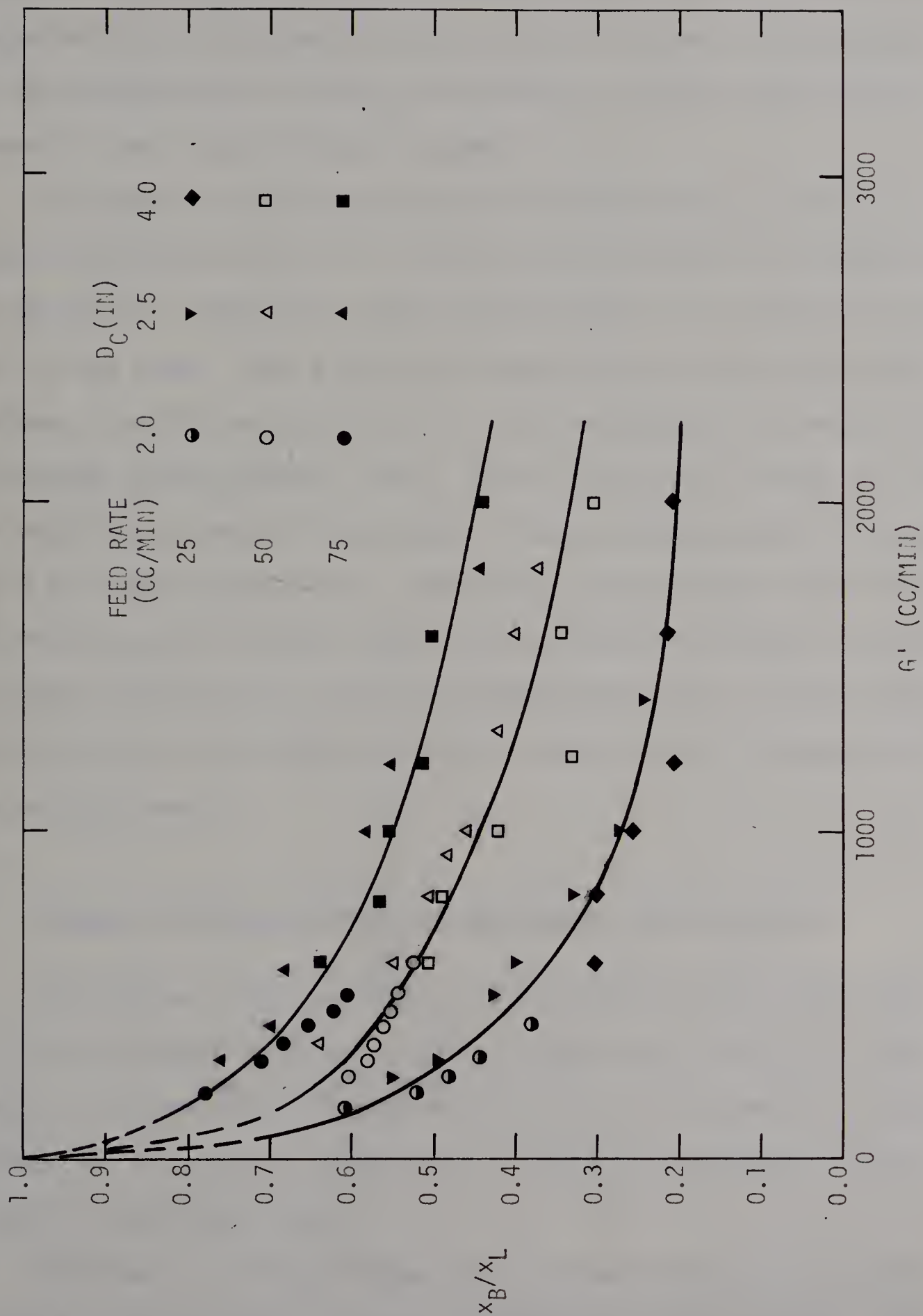


FIG. 11 EFFECT OF COLUMN DIAMETER AND FEED RATE ON STRIPPING RATIO

the ratio became smaller with increasing column diameter. The volume of entrained liquid decreased with the increase in column diameter because of the increased area available for drainage. A similar effect was observed at feed rates of 50 and 75 cc/min.

In Figure 11, the stripping ratio is plotted versus gas rate for each of the three feed rates. It can be seen that the drain concentration was essentially independent of the column diameter at a constant feed rate for all gas rates. With a constant liquid level of 14.0 inches in the columns, Tran (58) observed that the drain concentration increased with decreasing column diameter. With a liquid level of 14.0 inches the volume of liquid in 2.0 and 2.5 inch diameter columns would be equal to 44.0 and 68.75 cu. inches respectively. Since the volume of liquid in the columns in this study was 176.0 cu. inches, this resulted in an overall decrease in drain concentration. It can be concluded that with a constant volume of the liquid in the columns, the drain concentration is independent of the column diameter.

c. Effect of Diffuser Diameter on Continuous Foam Separation

The diffuser's only function is to distribute the gas effectively in the foam separation column, with the intention of producing a large amount of surface area. The separation that can be achieved in a column depends on the amount of surface area produced and consequently should depend on the diffuser area.

The effect of diffuser diameter on continuous foam separation was studied in two different columns of diameters 4.0 and 6.0 inches. The solution height above the diffuser was maintained constant at 14.0 inches

while the foam height was also constant at 53.5 inches above the interface. The diffusers used were made of porous brass and were designated as Brass-D1 and Brass-D2 with diameters of 1.25 and 2.5 inches respectively. Experiments were conducted for feed rates of 50 and 75 cc/min. For all tests, the feed concentration was maintained constant at 0.150 ± 0.002 g/l. A limited range of gas rates were covered. The results of experiments conducted with a 50 cc/min. feed rate are plotted in Figures 12 and 13. The abscissa represents the gas rate G' and the ratio B/L , and y_F have been chosen as ordinates.

Figures 12 and 13 show that

(1) The drain rate decreased with an increase in the size of the diffuser for a particular gas rate. The change in drain rate due to the size of the diffuser is more pronounced in the case of 4.0 inch diameter column than for the 6.0 inch diameter column. The change in drain rate with diffuser size is minimal for the 6.0 inch diameter column as the gas rate is increased but there is a significant change with an increase in gas rate for the 4.0 inch diameter column. When the size of the diffuser was increased the bubbles were distributed through more area into the liquid and the coalescence decreased. The foam thus produced was denser than the foam produced with a smaller diffuser. Since the surface area for entrainment increased with the size of the diffuser, the volume of entrained liquid also increased. Therefore, the ratio of drain rate to feed rate decreased with the increase in diffuser size. Similar results were obtained at the 75 cc/min. feed rate.

(2) The overhead concentration was essentially independent of diffuser diameter for the 4.0 inch column except at high gas rates. However, for

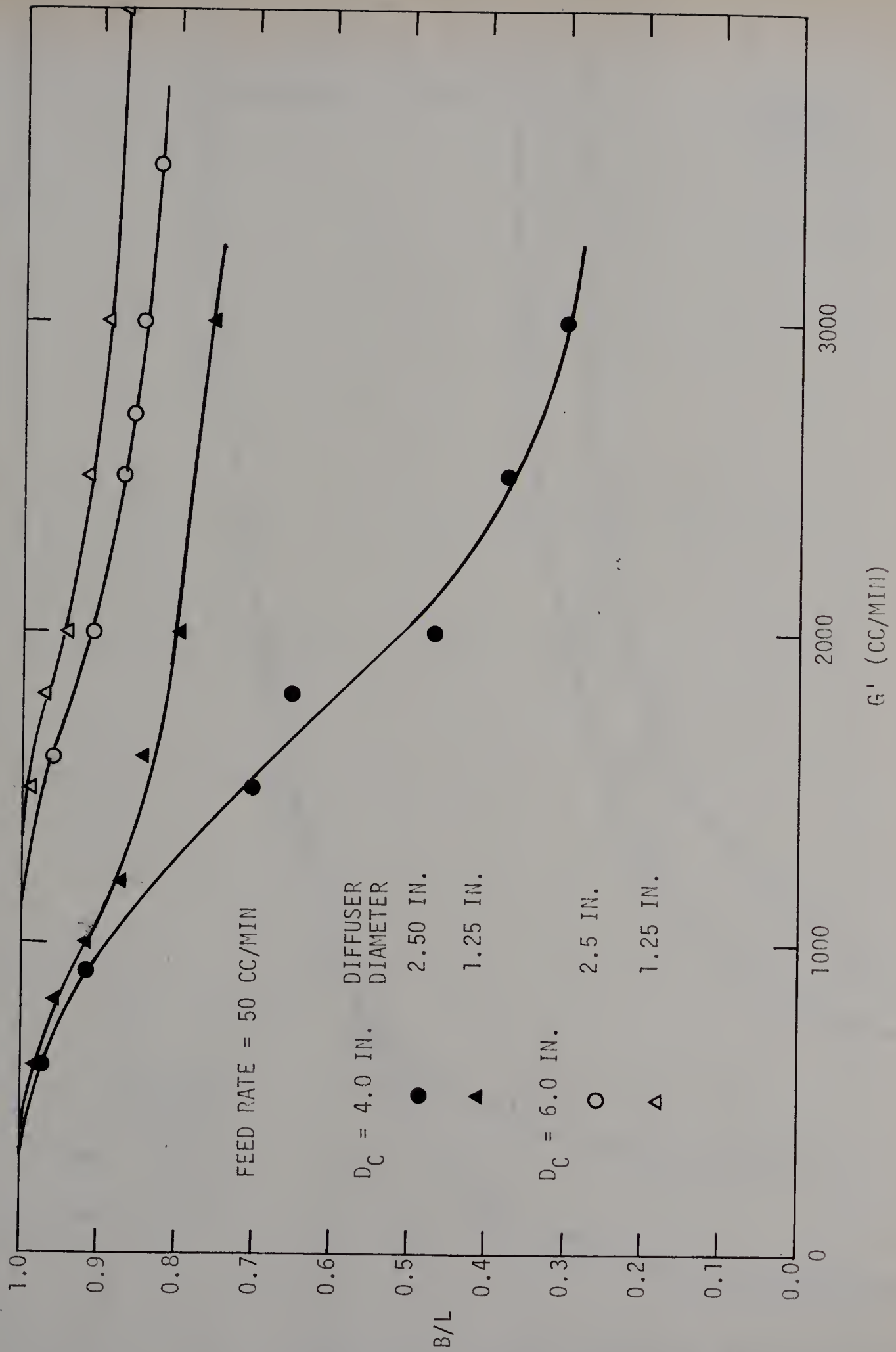


FIG. 12 EFFECT OF DIFFUSER DIAMETER ON DRAIN RATE

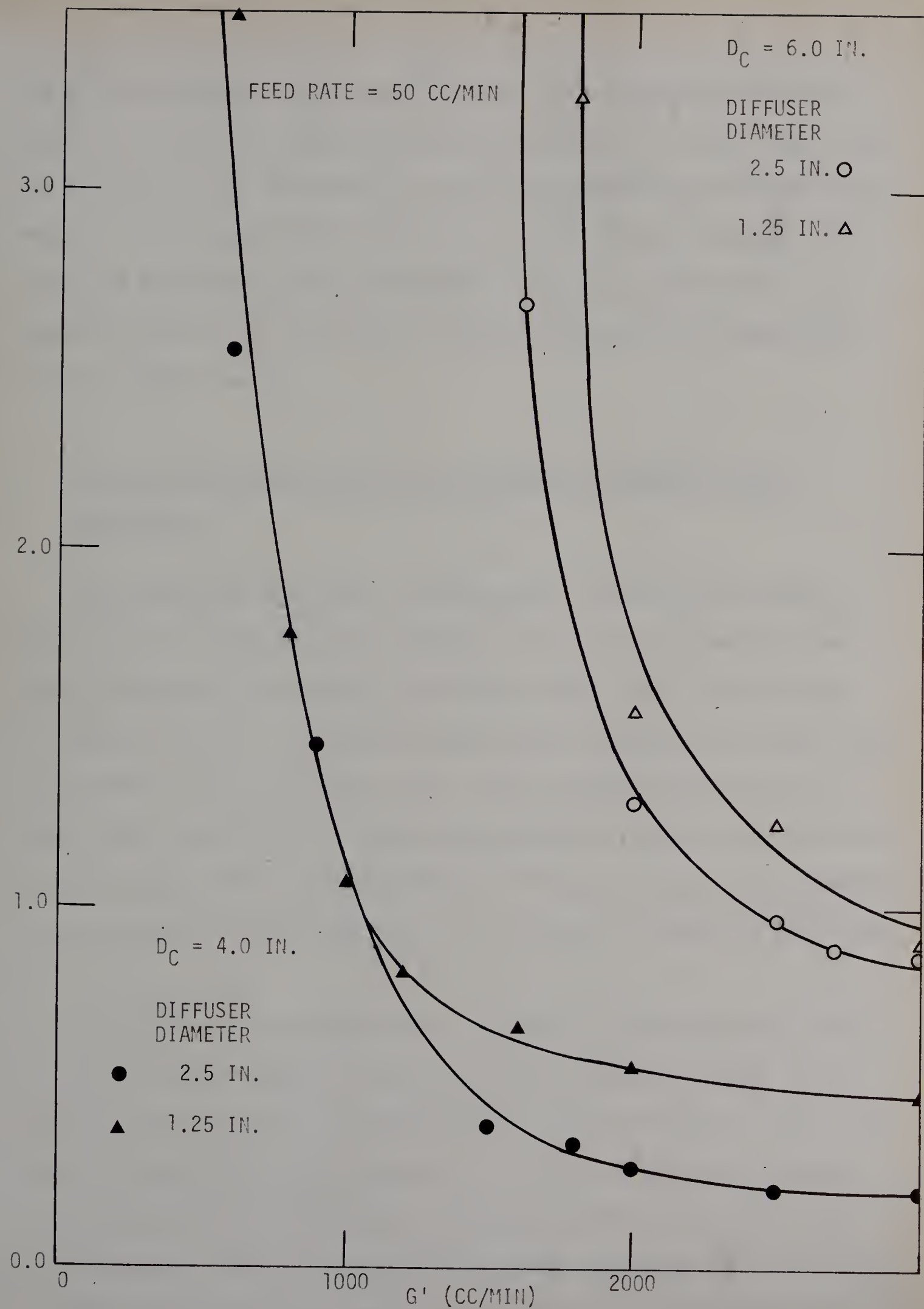


FIG. 13 EFFECT OF DIFFUSER DIAMETER ON
OVERHEAD CONCENTRATION

the 6.0 inch diameter column use of the 2.5 inch diameter diffuser resulted in a slightly lower overhead concentration at all gas rates. This was due to the fact that when the size of the diffuser was increased, the amount of entrained liquid in the foam was also increased because of the increased surface area for entrainment. It can be concluded that a decrease in the size of the diffuser increases the overhead concentration only by a small amount.

d. Effect of Mean Pore Size of the Diffuser on Continuous Foam Separation

The results of experiments conducted with the 4.0 inch diameter column using 2.5 inch diameter diffusers with pore sizes ranging from 5 to 130 microns, to determine the effect of mean pore size are shown in Figures 14 to 16. All the experiments were conducted for a feed rate of 50 cc/min., with the liquid level in the column maintained at 14.0 inches above the diffuser. Foam height above the interface was constant at 53.5 inches, while the concentration of the surfactant in the feed was also constant at 0.150 ± 0.002 g/l. The results in Figures 14 to 16 show that

(1) The drain rate increased with an increase in mean pore size of the diffuser at any gas rate but decreased rapidly with an increase in gas rate and levelled off at very high gas rates for diffusers of larger pore size. This was due to the fact that an increase in the mean pore size increased the size of the bubbles and decreased the total surface area for entrainment. Also, the amount of breakage increased with the increase in bubble size and thus decreased the volume of entrained liquid in the foam.

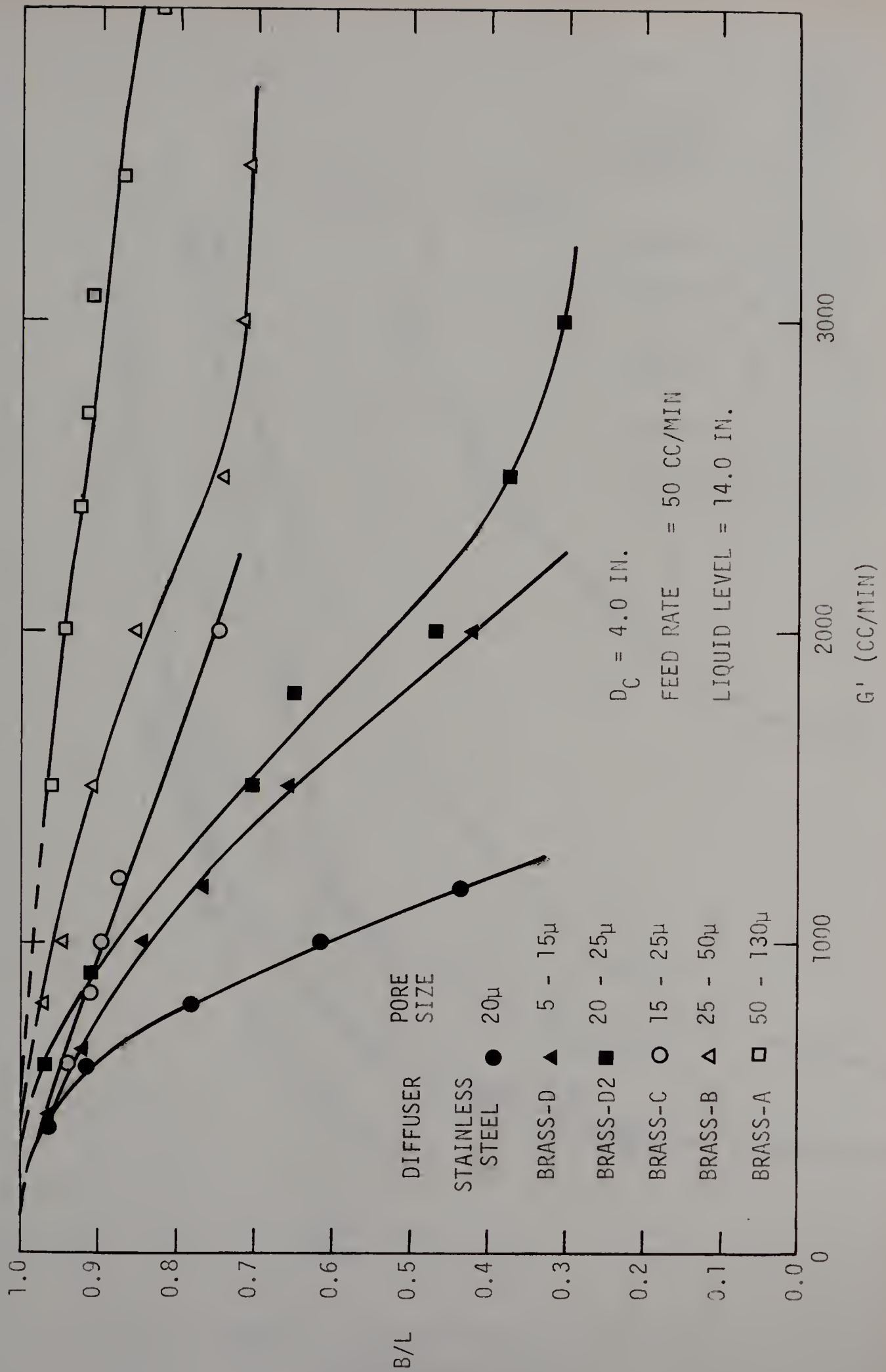


FIG. 14 EFFECT OF DIFFUSER MEAN PORE SIZE ON DRAIN RATE

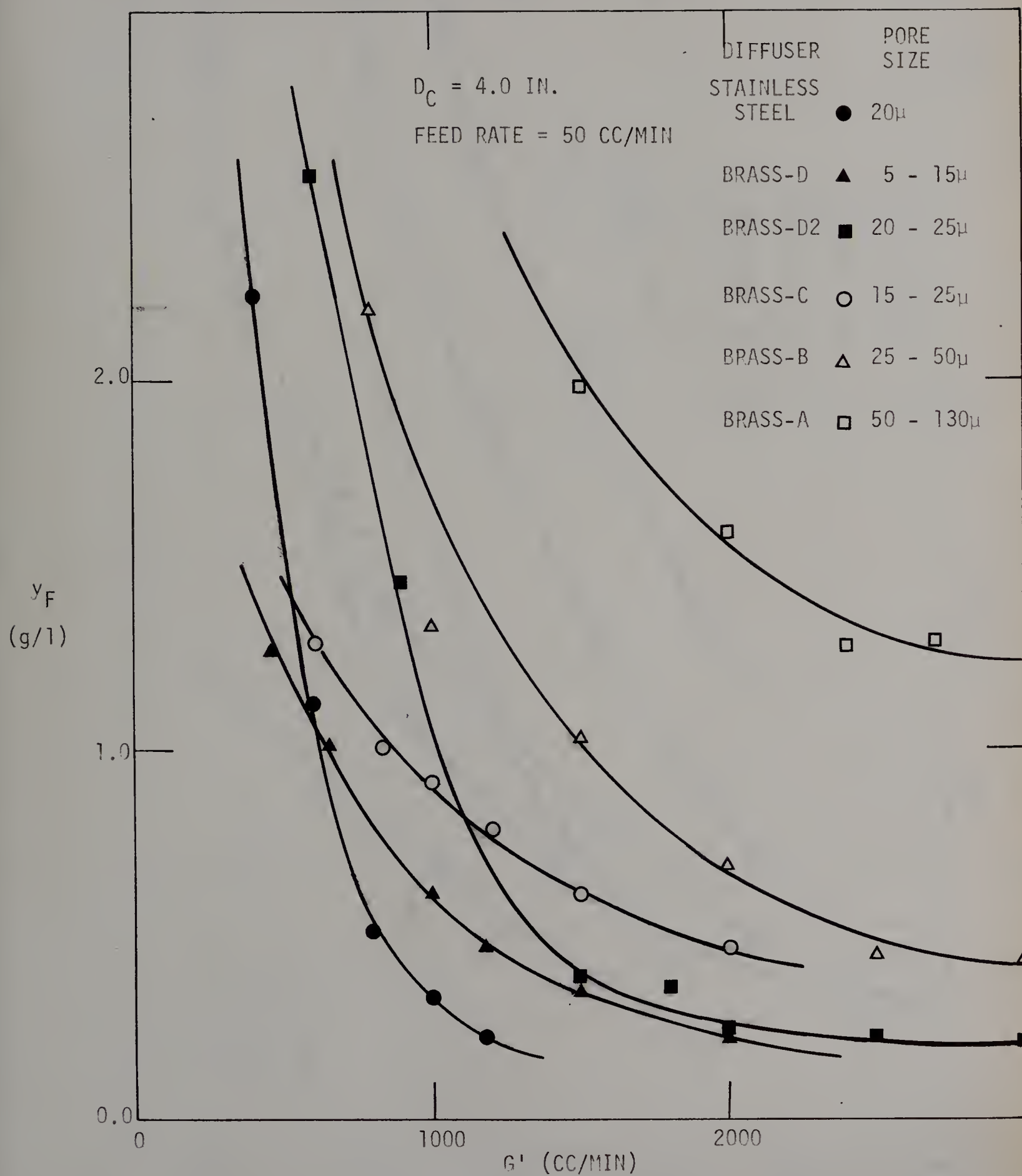


FIG. 15 EFFECT OF DIFFUSER MEAN PORE SIZE ON OVERHEAD CONCENTRATION

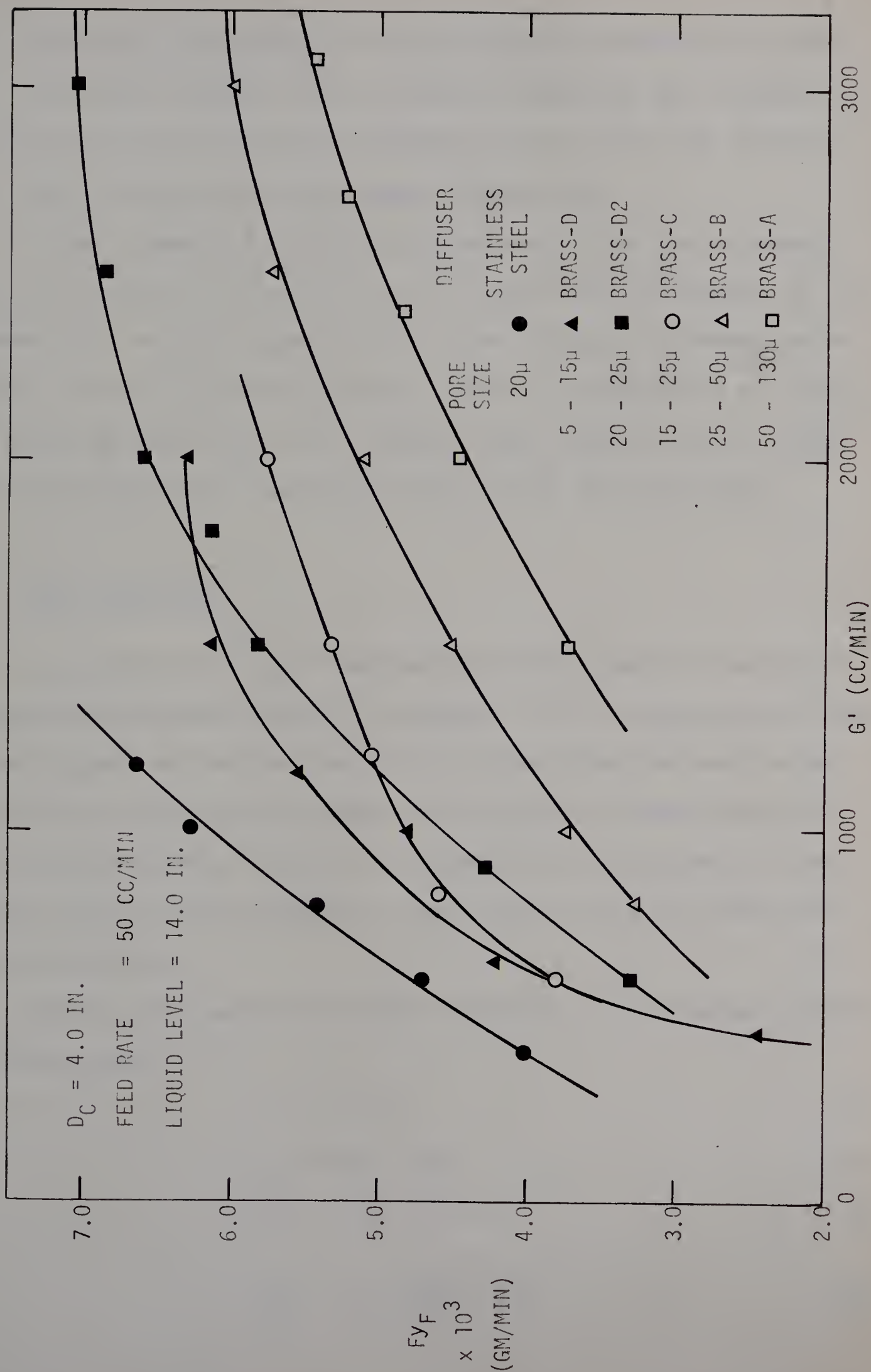


FIG. 16 EFFECT OF DIFFUSER MEAN PORE SIZE ON OVERHEAD SURFACTANT RATE

(2) The overhead concentration increased with the increase in the mean pore size of the diffuser. This is because of the fact that diffusers of high mean pore size lead to less entrained liquid in the foam yielding a dry foam of low density and thus higher concentration.

(3) The total amount of surfactant carried away in the foam decreased with the increase in mean pore size. This shows that the decrease in the overhead rate was not compensated for by the increase in overhead concentration. Hence intermediate mean pore sizes are desirable for an enriching operation since they yield a somewhat higher removal and also higher overhead concentration than would be the case for small pore sizes.

e. Ideal Foam Model

The concept of the ideal foam model and the assumptions involved in it have been described previously in Chapter III. The application of this concept depends entirely on the validity of the assumptions made in the formulation of the ideal foam model. The validity of these assumptions has been considered by Tran (58), on the basis of an experimental study. In this study a further attempt has been made to verify the validity of these assumptions.

Based on the concept of the ideal foam model, the following equations can be obtained:

$$L = F + B \quad (12)$$

$$Lx_L = Fy_F + Bx_B \quad (13)$$

$$Fy_F = Fx_B + G' A' \Gamma_B \quad (34)$$

$$\frac{x_L}{x_B} = 1 + \left(\frac{G' A'}{L} \right) \Gamma_B / x_B \quad (35)$$

where A' = surface area per unit volume of air in the foam.

Γ_B = equilibrium surface excess corresponding to the bulk phase concentration x_B .

The ratio (x_L/x_B) in equation (35) is the decontamination factor, D.F., for surfactant, and is one criterion of the performance of a column being operated for the removal of a surfactant. The equilibrium ratio Γ_B/x_B (the distribution coefficient) relates the amount of surfactant adsorbed at the interface to the concentration in the bulk phase. Equation (35) shows that two factors affect the D.F.; the ratio of physical flow rates $(\frac{G'A'}{L})$ which can be adjusted within limits; and the equilibrium ratio (Γ_B/x_B) which cannot.

If it can be assumed that the experiments are in the range of constant (Γ/x) values, then a plot of $\log (\text{D.F.} - 1)$ versus $\log (G')$ should yield a straight line with a slope of +1, provided that A' and L are kept constant. In Figures 17 and 18 $\log (\text{D.F.} - 1)$ is plotted against $\log (G')$ for different feed rates and different columns to test the validity of the assumptions. From Figures 17 and 18, it is evident that there is rather limited agreement between the experimental results and the theory, and only for a few cases are the data reasonably represented by a straight line with a slope of nearby +1. The disagreement is due to excessive foam breakage. It is assumed in the concept of ideal foam model that there is no bubble breakage in the foam before exit from the column. But this assumption is hardly valid and there is always internal reflux due to foam breakage. Only when the foam is extremely stable can it be said that the breakage is negligible. But in the system EHDA-Br-H₂O, the bubble breakage exists and hence the internal reflux is unavoidable.

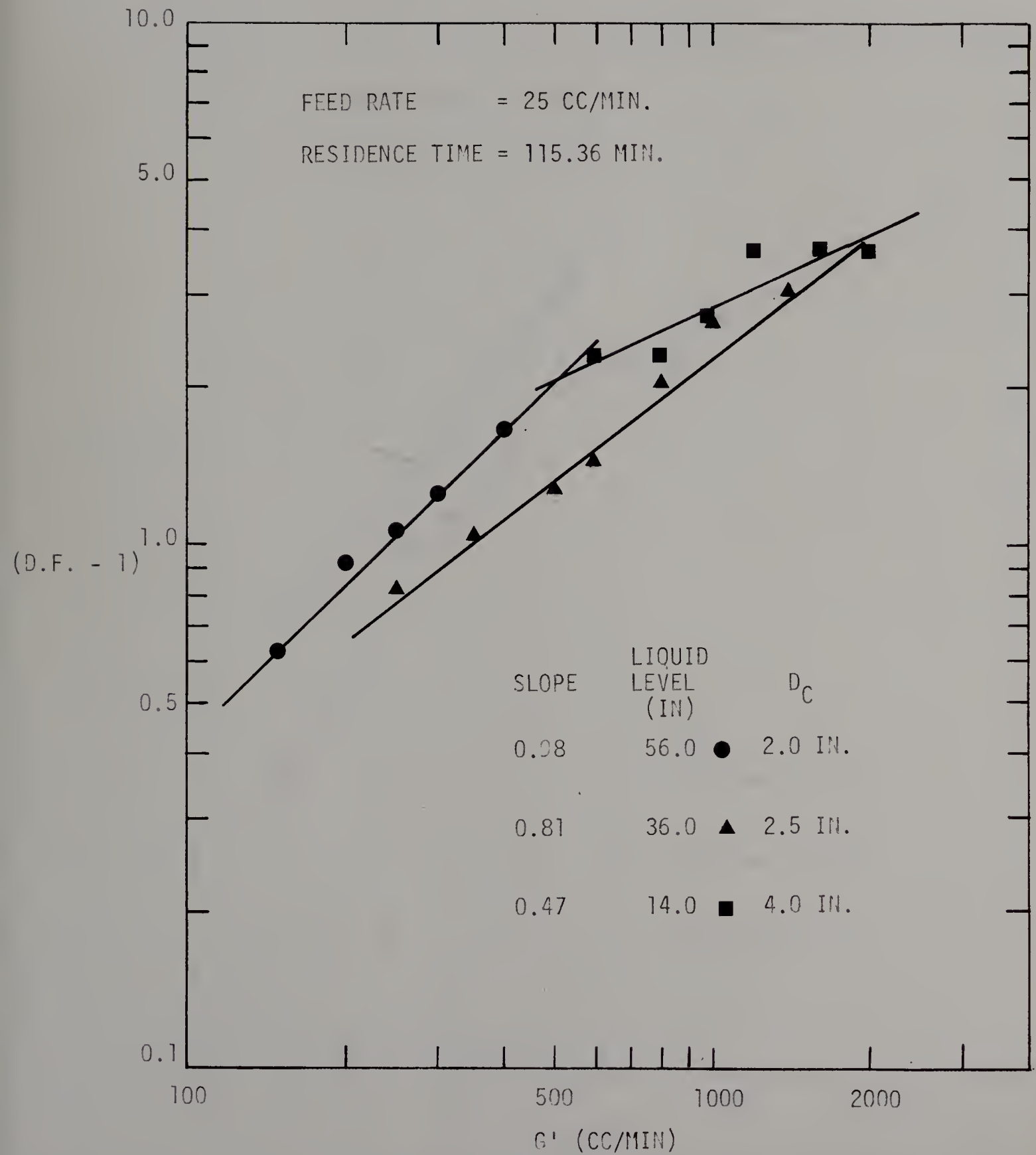


FIG. 17 EFFECT OF AIR FLOW RATE ON SURFACTANT REMOVAL

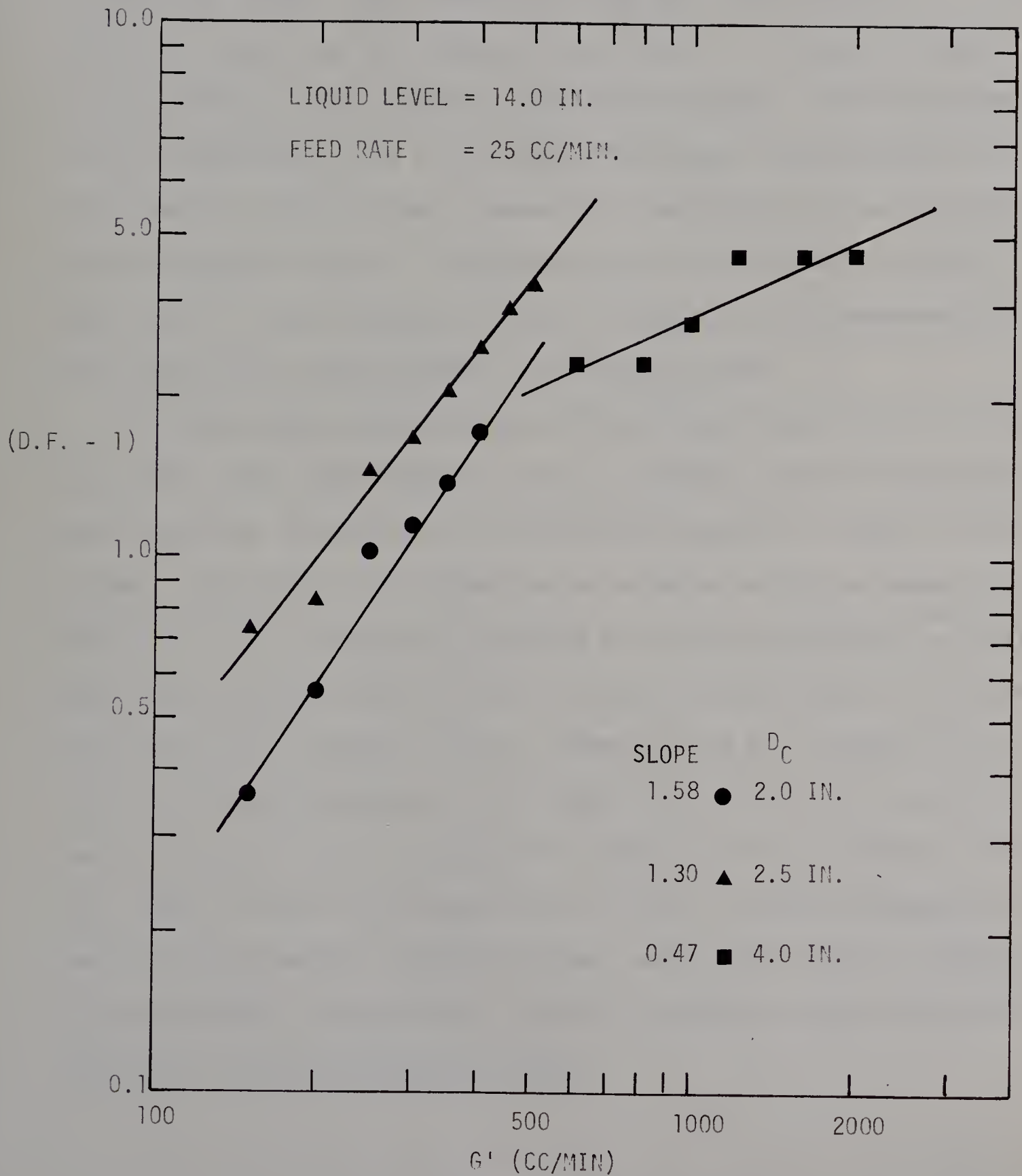


FIG. 18 EFFECT OF AIR FLOW RATE ON
SURFACTANT REMOVAL

From these Figures, it is also evident that a slope of greater than +1 results in a larger change in the drain concentration corresponding to a particular change in gas rate than in the case with a slope of +1. The contrary is also true for a slope of less than +1. In general, it can be concluded that the assumptions made in the concept of ideal foam model are only reasonably valid in the case of continuous foam separation, at least for the present system. Newson (31) investigated the validity of these assumptions based on this approach and arrived at the conclusion that there is a good agreement between the theory and the experiments for the system sodium dodecylbenzene sulphonate and water.

The foam column used by Newson (31) was made of two 1 ft. x 1-1/2 in. bore pyrex tubes bolted together across a polythene gasket through which feed liquid was injected into a liquid pool of about 2 ft. depth in the column. The bottom of the column had an expanded section to house the drain port. The interface was adjusted to allow only moderate foam drainage so that the sphericity of the air bubbles was maintained in the foam phase right up to the exit from the column. Hence the assumption that there is no bubble breakage in the column before the exit of foam was valid and so the results obtained were comparable with the theory. In this study no special effort was made to prevent the foam breakage and hence the experimental conditions did not comply fully with the theoretical requirements. Consequently a limited agreement was observed between the theory and the experimental results.

2. Kinetic Approach

The kinetic approach to explain the separation in a continuous foam separation column is relatively a new one. Rubin et. al. (59) have considered the analysis of batch operation by the kinetic approach but no attempt has been made so far to explain the continuous foam separation on this basis. Continuous foam separation can be considered by relating it to the operation of a continuous stirred-tank reactor or a steady state backmix reactor. The rate of foam separation is considered to be analogous to the rate of reaction and a rate equation is derived on this basis. For continuous foam separation the rate equation is given by equation (31) as

$$r = \frac{F \cdot y_F}{\tau \cdot L} \quad (31)$$

The characterization of the foam separation process is now considered on this basis. Since the rate of reaction is evaluated from exit stream conditions, which are the same as the conditions within the reactor a similar approach is adopted in treating the rate of separation. Therefore, the rate is plotted versus the drain concentration for columns of diameters 2.0, 2.5, 4.0 and 6.0 inches, in Figures 19 to 22. Also, the drain concentration is a strong function of gas rate and the effect of gas rate on x_B can therefore be obtained from Figures 5 and 6. The effect of the remaining variables such as feed rate, liquid height, column diameter and diffuser mean pore size can be seen from Figures 19 to 22.

Figure 19 represents the effect of column diameter on the rate of separation for a constant liquid level of 14.0 inches above the diffuser for feed rates of 25, 50 and 75 cc/min. The rate of separation decreased

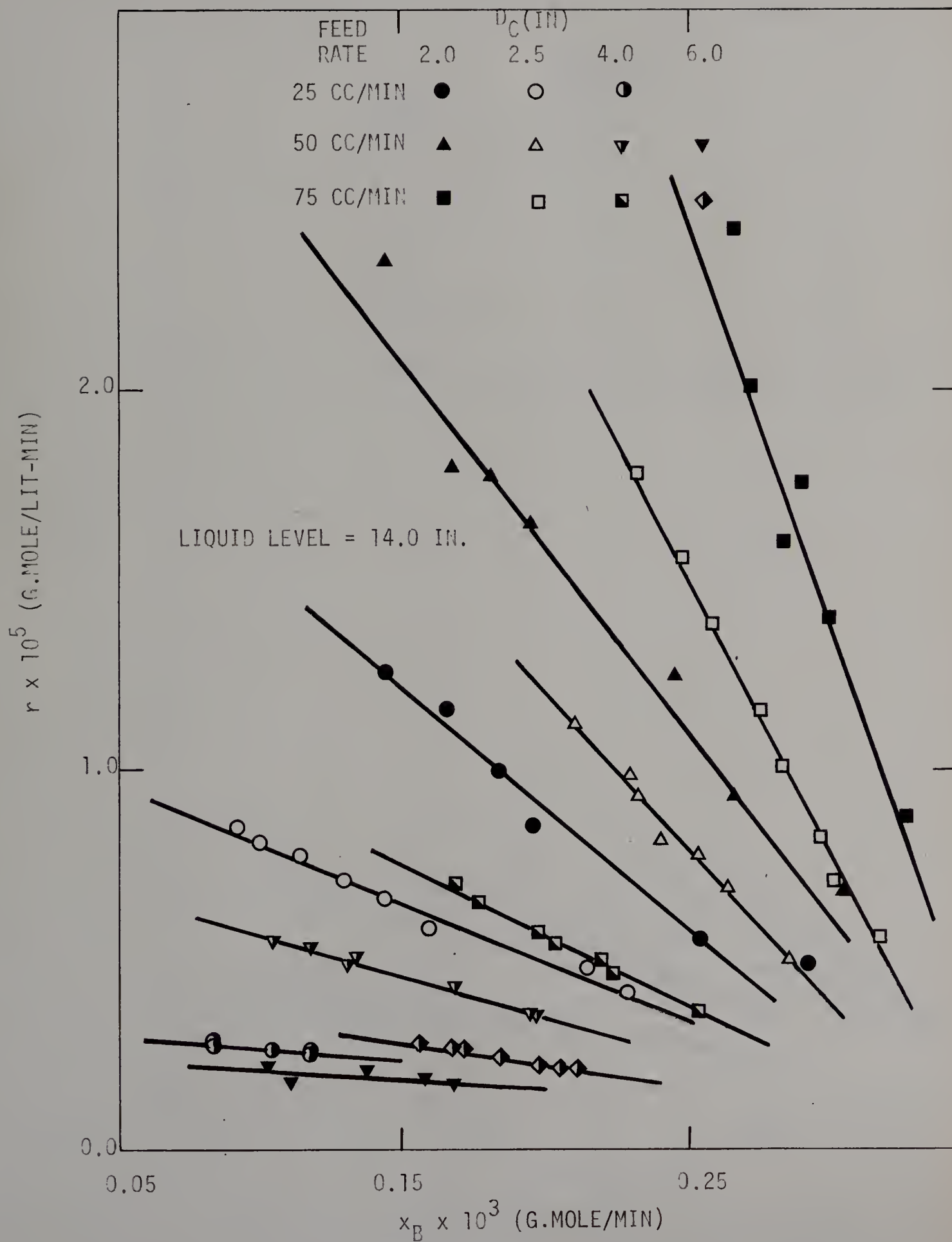


FIG. 19 EFFECT OF FEED RATE AND COLUMN DIAMETER ON RATE OF FOAM SEPARATION

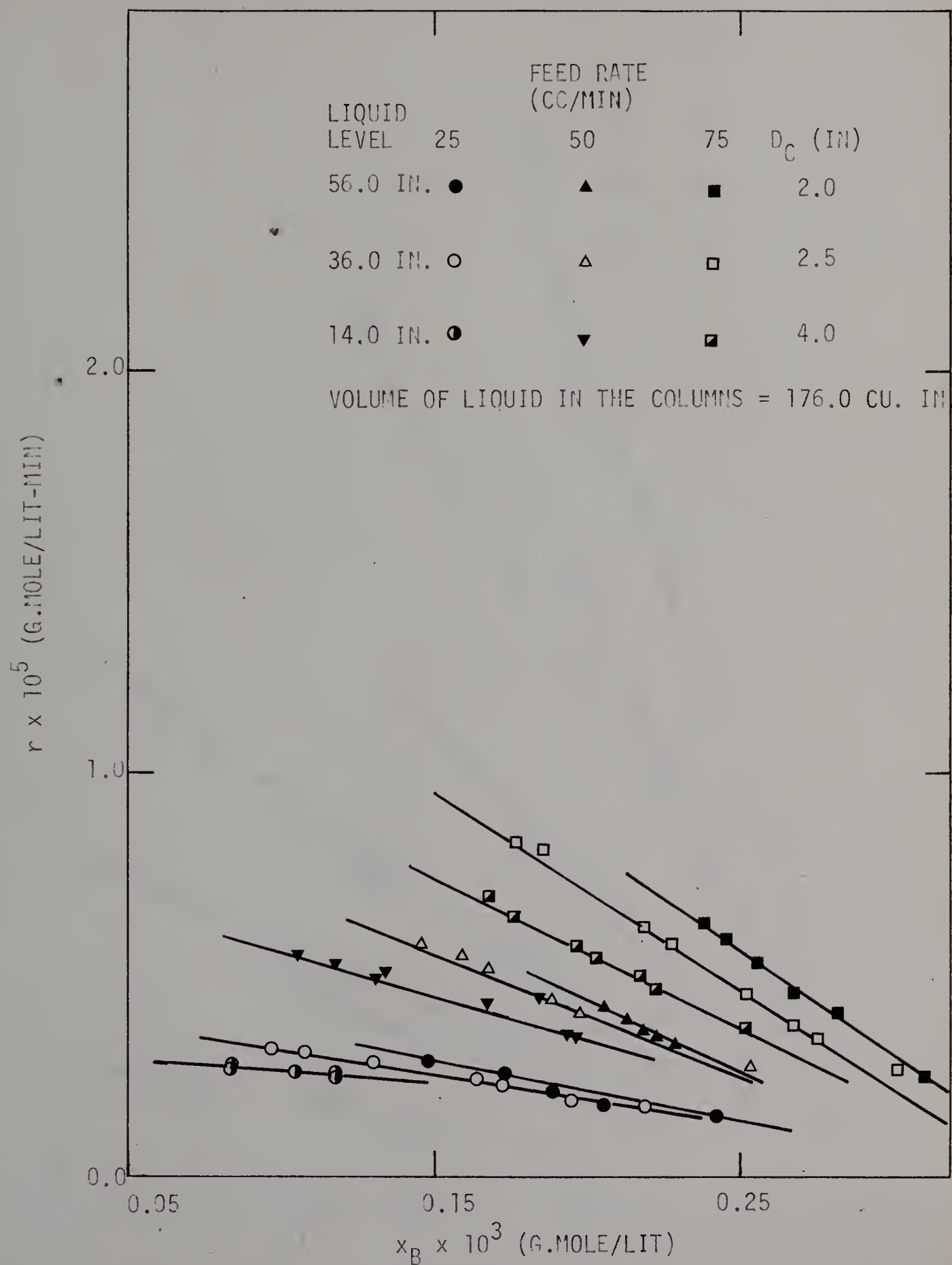


FIG. 20 EFFECT OF COLUMN DIAMETER WITH CONSTANT VOLUME OF LIQUID IN THE COLUMNS, ON RATE OF FOAM SEPARATION

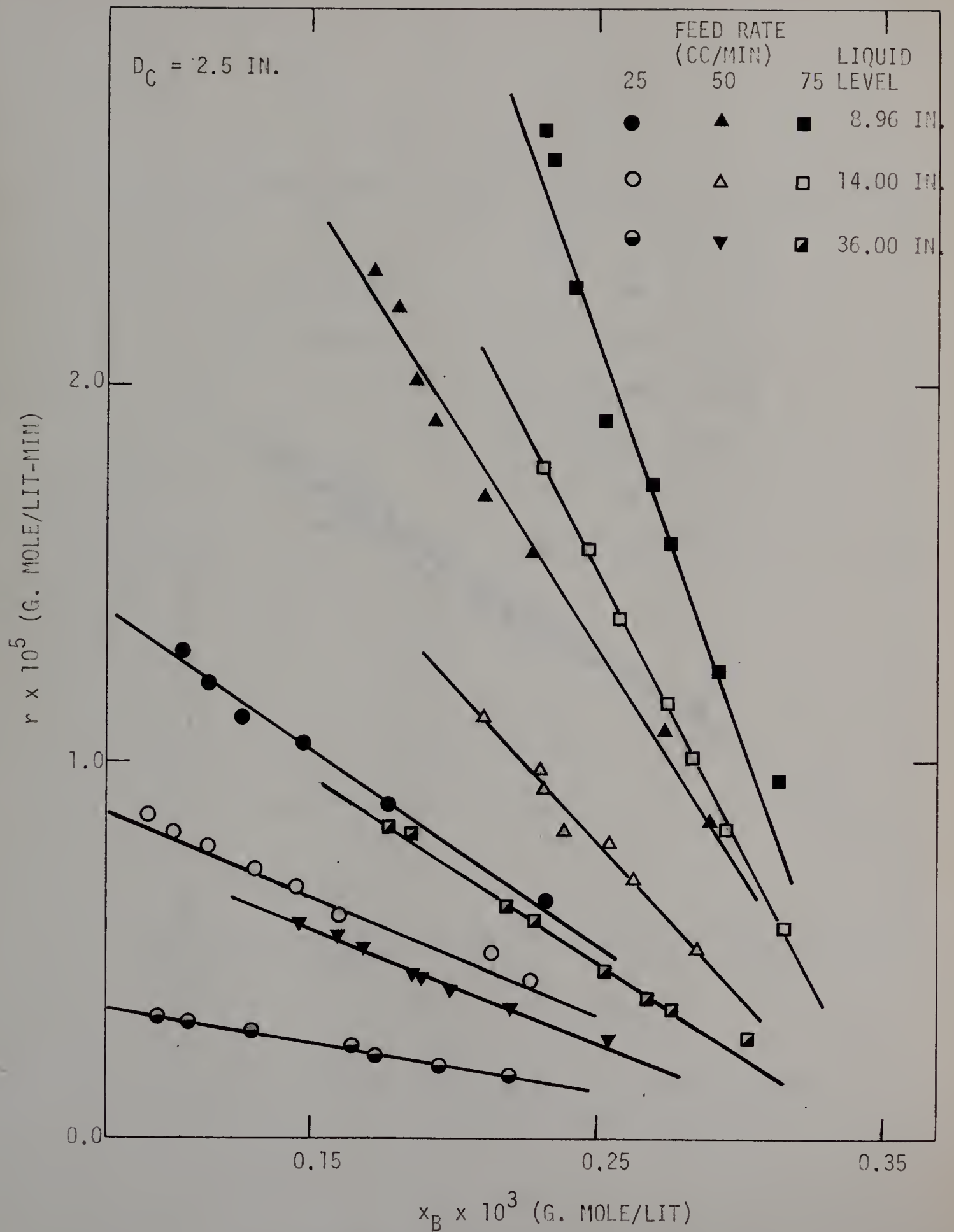


FIG. 21 EFFECT OF LIQUID LEVEL AND FEED RATE
ON THE RATE OF FOAM SEPARATION

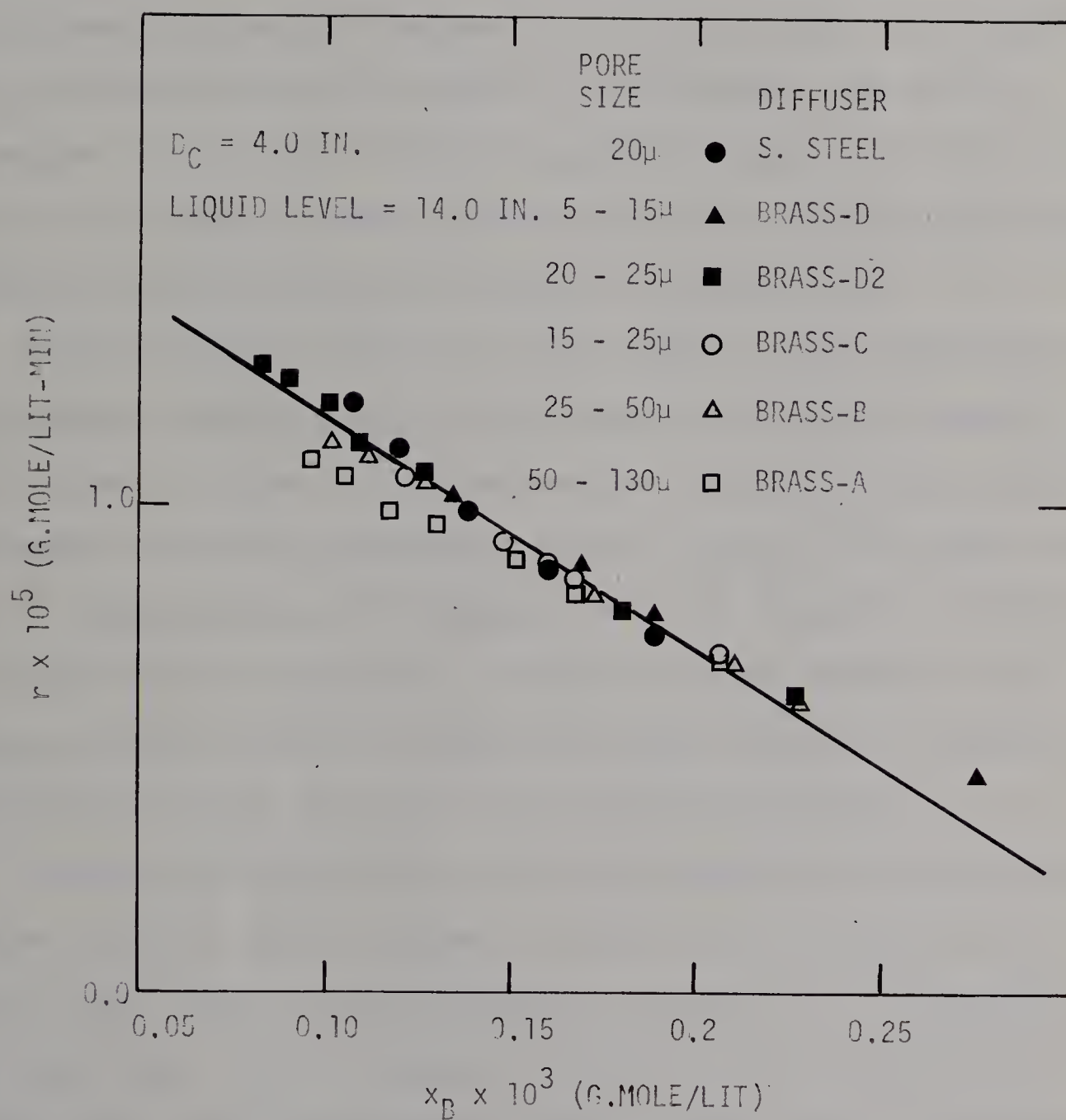


FIG. 22 EFFECT OF DIFFUSER PORE SIZE ON THE RATE OF FOAM SEPARATION

with increasing drain concentration and for the same drain concentration the rate decreased with an increase in the column diameter. This is expected because in addition to the increase in column diameter, thus increasing the residence time, the rate of foamate decreased even though the overhead concentration increased. It is also evident from Figure 19 that an increase in feed rate results in an increase in the rate of separation. This is due to the fact that the increase in feed rate resulted in an increased overhead concentration thus increasing the rate of removal without significantly changing the foamate rate.

Figure 20 shows the effect of column diameter on the separation rate with the same volume of liquid in the columns for columns of diameter 2.0, 2.5 and 4.0 inches. It can be seen that the rate of separation or the amount of surfactant transferred per unit volume of the column liquid per unit time increased with a decrease in column diameter. The volume of liquid in all the columns was the same but as the diameter of the column increased, the rate of foamate decreased tremendously and was not compensated for by an increase in the overhead concentration.

The effect of liquid level on the rate of separation for a 2.5 inch diameter column is shown in Figure 21, where it can be seen that for a constant feed rate, the rate of separation increased with a decrease in the liquid level. This is because a decrease in the liquid level in a column reduces the liquid residence time and unless there is a decrease in the surfactant in the overhead stream then the rate of separation must decrease. The same effect was observed in the case of a 2.0 inch diameter column. The effect of feed rate on the separation is also evident in Figure 21.

Figure 22 shows the effect of mean pore size of the diffuser on the rate of separation for a 4.0 inch diameter column with a feed rate of 50 cc/min. The liquid level in the column was kept constant at 14.0 inches above the diffuser while the foam height was also constant at 53.5 inches above the interface. Figure 22 shows that the rate of separation is independent of the mean pore size for a particular drain concentration despite the fact that the overhead concentration increased with the increased mean pore size. However, because of the simultaneous decrease in the foamate rate, the rate of separation remained constant.

Considering Figures 19 to 22, it can be concluded that it is the total amount of liquid in the column that determines the amount of surfactant transferred per unit volume of the column liquid per unit time. Hence, for an enriching operation requiring a constant drain concentration a smaller column is preferred since the amount of surfactant transferred per unit volume per unit time is higher for a smaller column. From these figures it can also be seen that the relationship between the rate of separation and the drain concentration is a straight line relationship with a negative slope. Hence, the rate of separation can be expressed as

$$r = k_1' - k_2' x_B \quad (36)$$

where k_1' = intercept

k_2' = slope

x_B = drain concentration, (g mole/litre).

The slope and the intercept are functions of the feed rate, diameter of the column and the liquid height. Hence, k_1' and k_2' are plotted versus

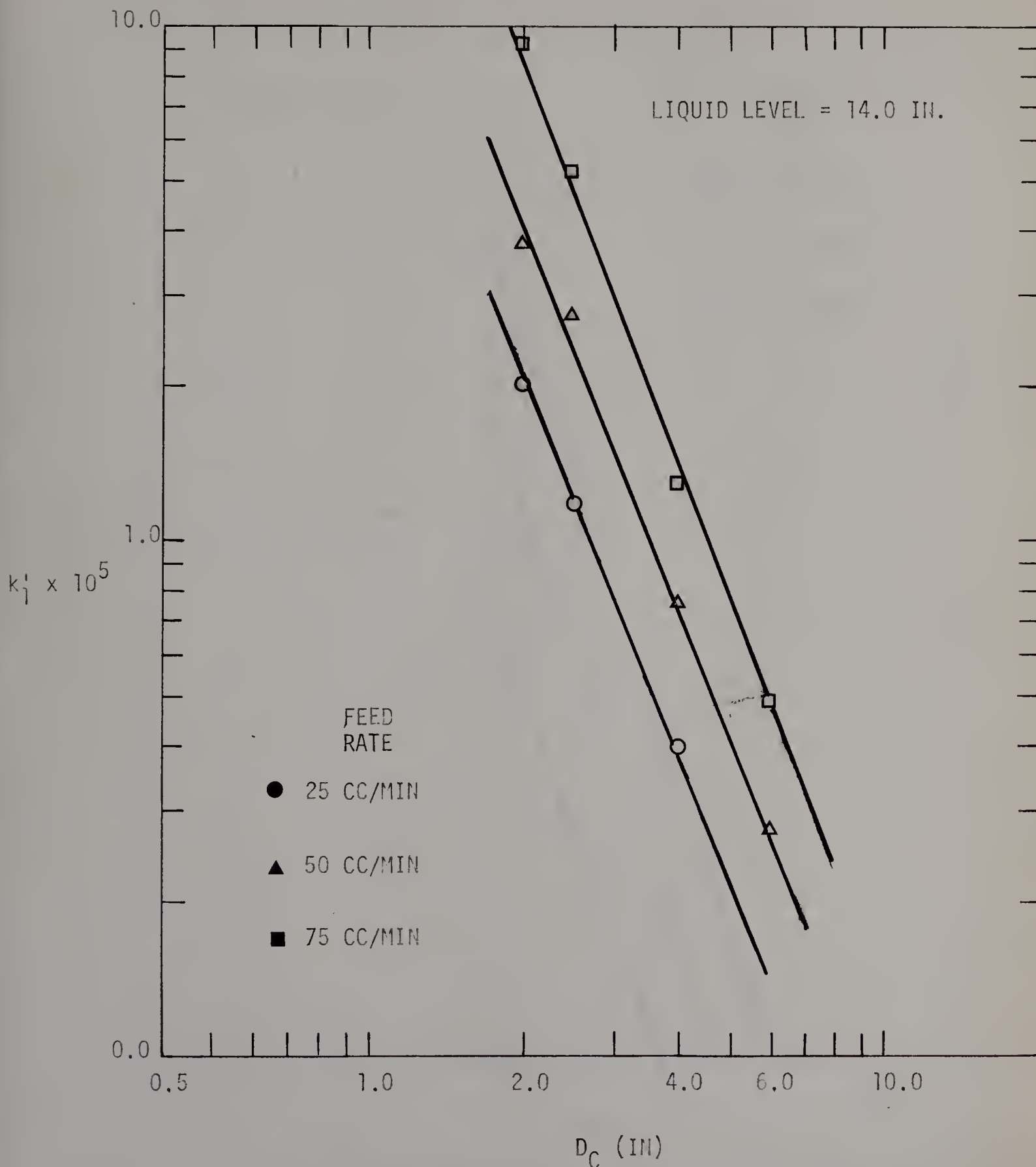


FIG. 23 RELATIONSHIP BETWEEN THE INTERCEPT OF THE RATE EQUATION AND COLUMN DIAMETER FROM VARIABLE FEED RATE EXPERIMENTS

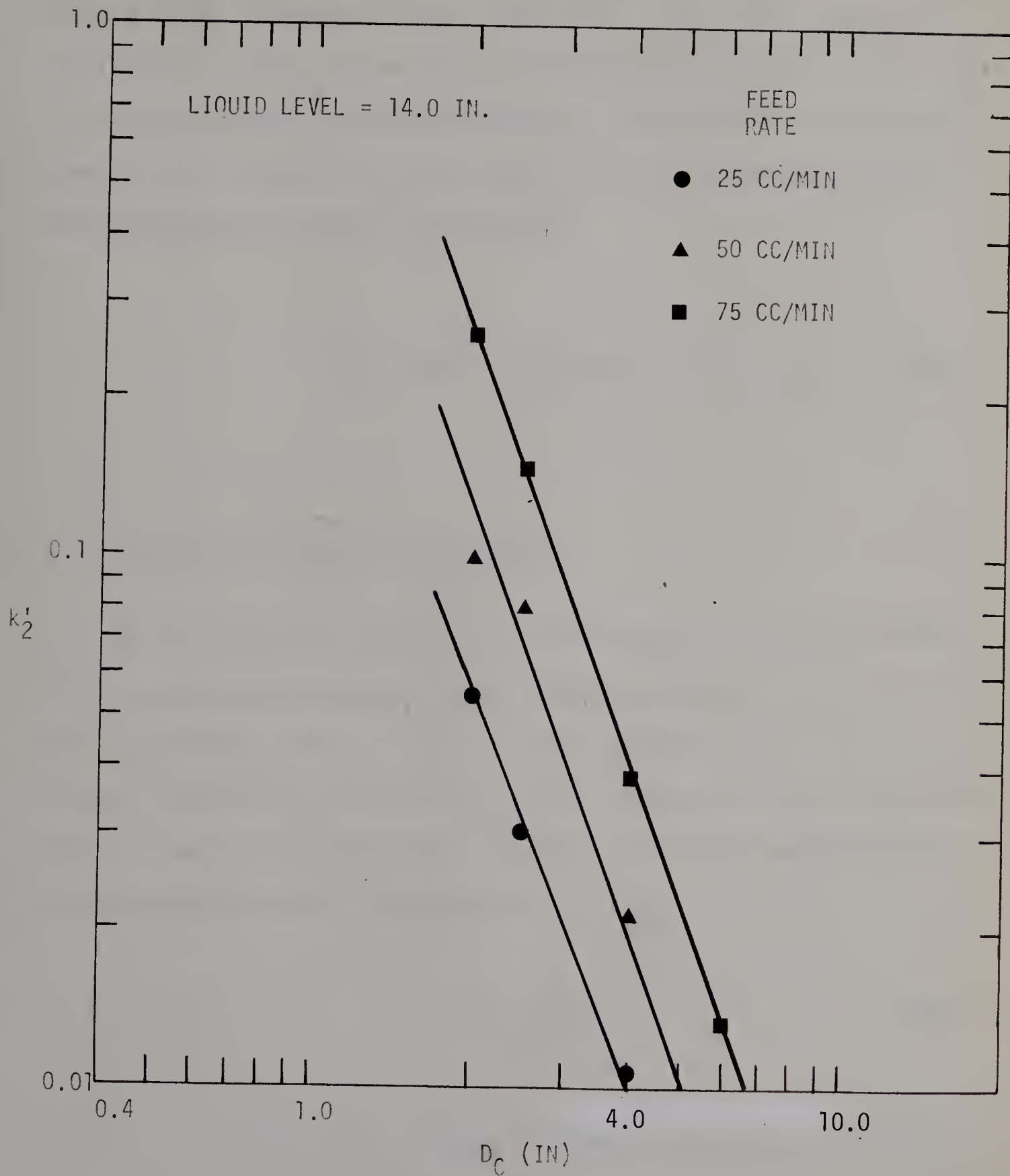


FIG. 24 RELATIONSHIP BETWEEN THE SLOPE OF THE RATE EQUATION AND COLUMN DIAMETER FROM VARIABLE FEED RATE EXPERIMENTS

diameter of the column in Figures 23 and 24, for a constant liquid level of 14.0 inches and each of three feed rates. From these figures, the relationship between the operating variables and the intercept and slope of the rate expression were determined. It was found that for a liquid level of 14.0 inches in all the columns, the rate of separation can be expressed by the following relationship:

$$r = 0.14 \times 10^{-2} \frac{L^{1.4}}{D_C^{2.5}} (5.64 \times 10^{-4} - x_B) \quad (37)$$

3. Properties of Dynamic Foam Columns

The properties of aqueous stable foams moving in vertical columns for the system Arsket-300-H₂O were studied by Rubin et. al. (61) in 1967. They investigated the foam ratio, f , as a function of gas flow rate, surfactant concentration, foam height, bubble diameter and foam column diameter. They also expressed the foam ratio in terms of experimental variables by the general relationship

$$f = K \frac{u_f}{d^2 D_C^{0.2}} \quad (38)$$

where f = foam ratio (volume fraction of the liquid in the foam), dimensionless.

K = f/f_{PB} .

f_{PB} = fractional cross-section available for liquid flow.

u_f = foam velocity, (cm/sec).

$\bar{d}$ = average bubble diameter, (cm).

D_c = column diameter, (cm).

The applicability of this correlation for the system EHDA-Br-H₂O is considered using experimental data obtained from all four columns. The average bubble diameter was calculated from the theoretical expression (58),

$$\bar{d} = \left\{ \frac{6D'}{g(\rho_l - \rho_g)} \right\}^{1/3} \gamma^{1/3} \quad (39)$$

where $\bar{d}$ = average bubble diameter, (cm).

D' = orifice diameter, (cm).

ρ_l = density of liquid.

ρ_g = density of gas.

g = acceleration of gravity.

γ = surface tension of the solution.

In the use of equation (39), the surface tension of the solution was obtained from the data presented by Tran (58). The results of this study are plotted in accordance with the scheme suggested by Rubin et. al. (61). Figure 25 is a graph of $\log(f \cdot \bar{d}^2)$ versus $\log(u_f)$ for data obtained with the 4.0 inch diameter column with a feed rate of 50 cc/min and for various porosity diffusers. Rubin et. al. used such a representation for data taken with a recirculatory foam column, 2.46 cm. in diameter and with a foam column height of 45 cms., with a wider bottom portion for the solution. The results obtained by Rubin et. al. could be represented by a single line for all the spargers used (with hole diameters of 0.03,

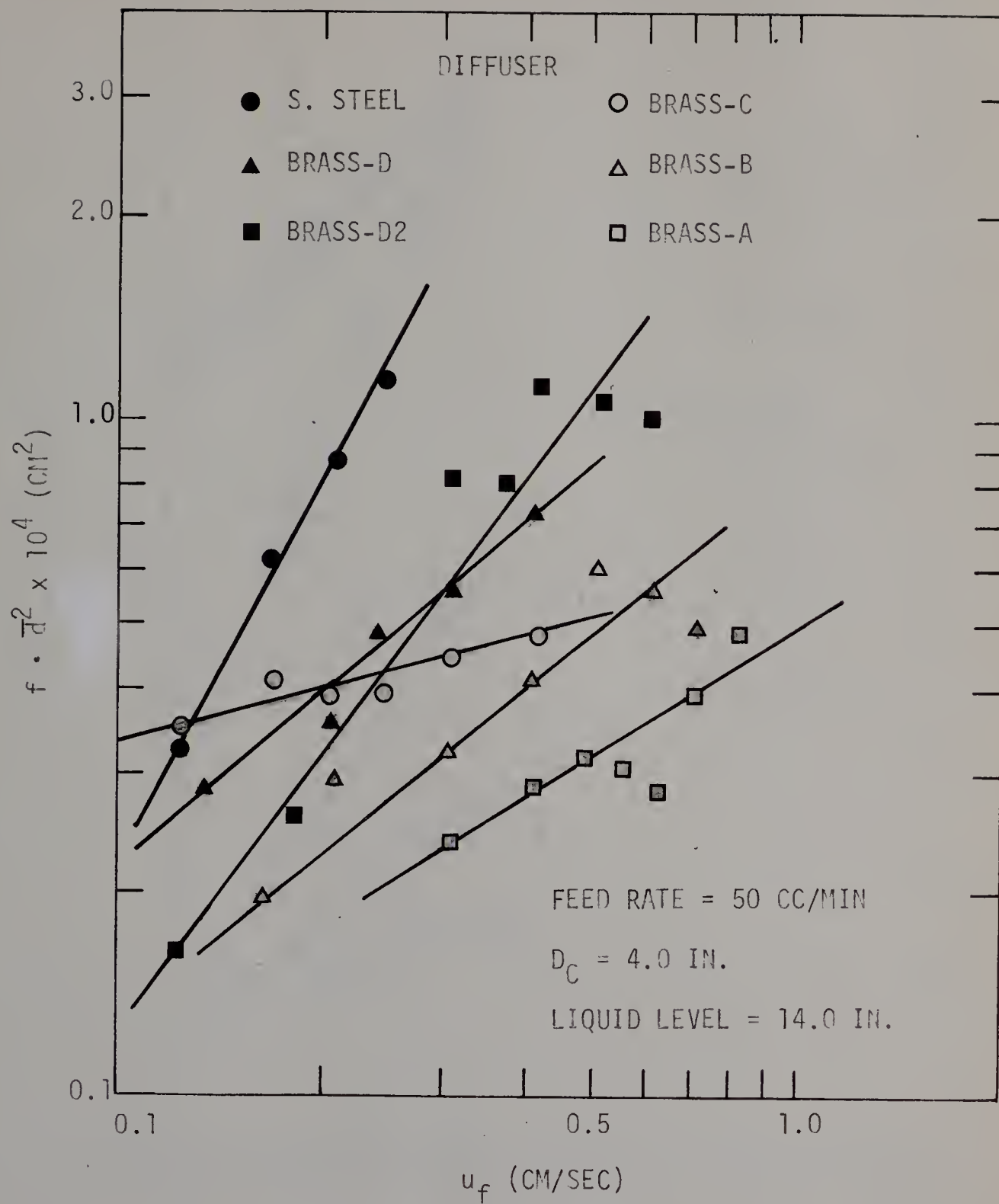


FIG. 25 CORRELATION FOR A WIDE BUBBLE
DIAMETER RANGE

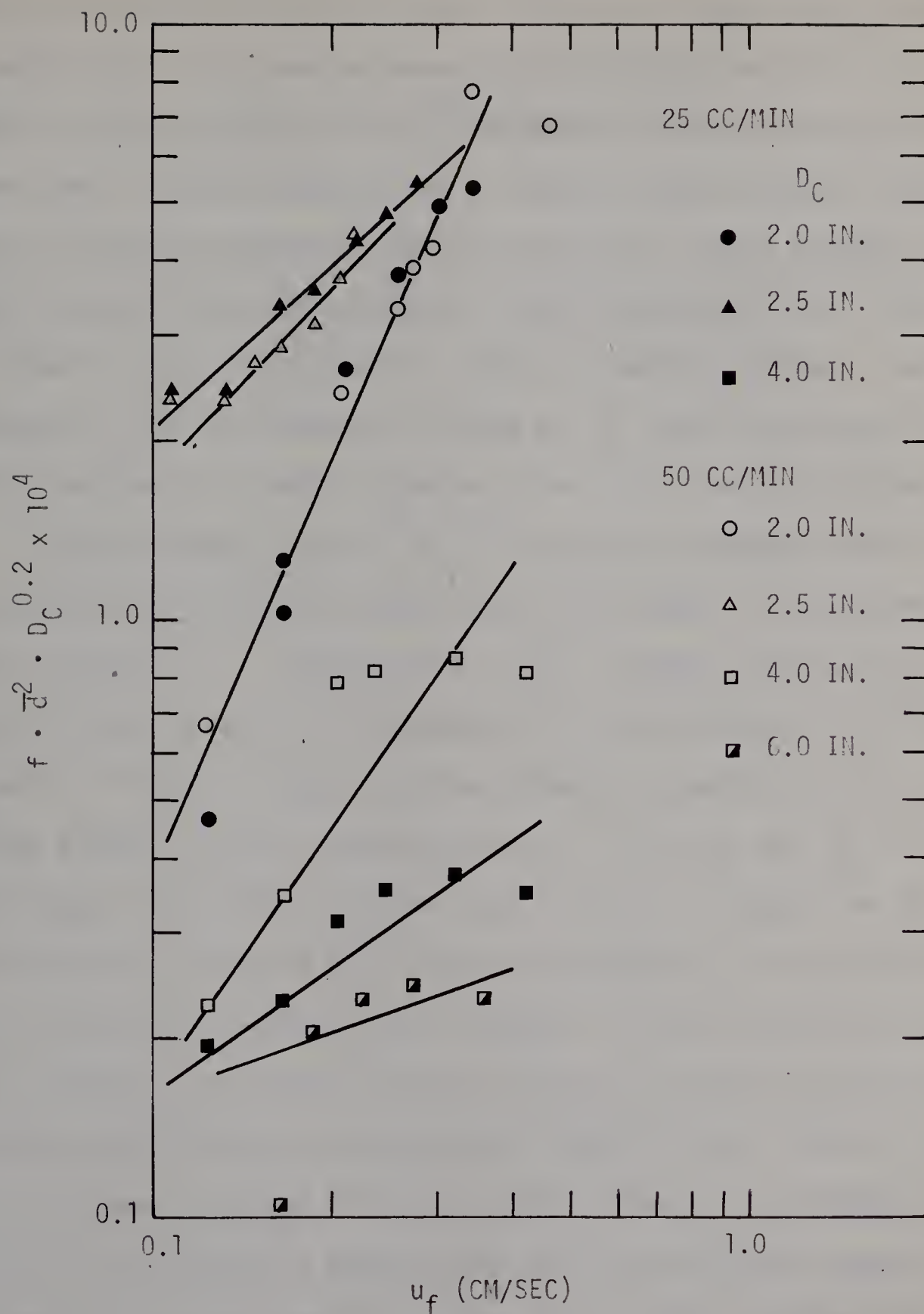


FIG. 26 CORRELATION FOR EFFECT OF COLUMN DIAMETER AND FEED RATE

0.05, 0.07 mm., and coarse fritted glass sparger). Figure 25 shows that the data obtained with each diffuser can only be represented by separate straight lines. The results shown in Figure 25 indicate that for a given foam velocity, the value of $(f \bar{d}^2)$ decreased with the increase in the mean pore size. This was probably due to excessive foam breakage occurring with an increased mean pore size and also with a larger diameter column. Since the entrainment increased with smaller diameter column, the change in foam ratio was compensated by changes in bubble diameter. The foam breakage in the investigation of Rubin et. al. should have been insignificant because of a smaller diameter column and a low foam column height.

Figure 26 shows $\log (f \bar{d}^2 D_c^{0.2})$ plotted as ordinate versus $\log (u_f)$ as abscissa for different columns used in the study. A corresponding plot by Rubin et. al. showed that a single straight line would represent the data from columns of all diameters and with diffusers of different porosity. Figure 26 shows that the ordinate increased with the decreasing column diameter for the same foam velocity. This was due to the increased entrainment with smaller columns which in effect increased the foam ratio. The addition of the term $D_c^{0.2}$ could not compensate for the decrease in foam ratio with increasing column diameter. Leonard and Lemlich (62) also reported a consistent deviation between experiment and theory for the few experiments they conducted with dynamic foams. Another explanation that could be given is that the bubble diameter calculated in this study by the theoretical equation may not be satisfactory compared to the measured bubble diameter by Rubin et. al. Also, the foam velocity which was measured by Rubin et. al. in their investigation was calculated in this study by the expression

$$u_f = \left\{ \frac{F + G'}{\pi/4 D_c^2} \right\} \quad (40)$$

where F = Foamate rate (cm^3/min).

G' = Gas rate, (cm^3/min).

Hence, it can be concluded that the correlation presented by Rubin et. al. can not be applied satisfactorily for the present system.

VI. CONCLUSIONS

The continuous foam separation of EHDA-Br-water system has been studied to investigate the effects of operating variables on the separation. From the experimental data obtained with four columns of diameters 2.0, 2.5, 4.0 and 6.0 inches for three feed rates of 25, 50 and 75 cc/min. with different diffusers, the following conclusions are made.

1. Effect of Operating Variables on Separation

a. Effect of Residence Time

(i) Effect of Residence Time by Varying the Feed Rate

It was found that with a constant liquid level of 14.0 inches in the columns, the drain rate and the drain concentration were affected by the changes in liquid residence time by varying the feed rate. The effect was more pronounced in the case of smaller diameter columns. For example, for a 2.0 inch diameter column with a constant gas rate of 300 cc/min., B/L increased from 0.576 to 0.808 for an increase in feed rate from 25 cc/min. to 50 cc/min. For the same gas rate, further increase in feed rate to 75 cc/min. increased B/L to 0.852. Similarly, for a 2.5 inch diameter column and for a gas rate of 400 cc/min. B/L increased from 0.409 at 25 cc/min. to 0.672 at 50 cc/min. The range of gas rate covered was higher for a 4.0 inch diameter column. Also, the increase in B/L with an increase in feed rate was lower with larger diameter columns. For example, at a gas rate of 1000 cc/min. for a 4.0 inch diameter column, B/L increased from 0.909 at 25 cc/min. to 0.914 at 50 cc/min. A further increase in feed rate to 75 cc/min. resulted in an increase in B/L to 0.929.

The drain concentration increased with increasing feed rate in all the columns. For example, for a 2.5 inch diameter column, the drain concentration increased from 0.0560 gm/l at a feed rate of 25 cc/min. to 0.0910 gm/l at a feed rate of 50 cc/min. for a constant gas rate of 300 cc/min. Some of the changes in B/L and x_B/x_L with feed rate are given in Table (VI-1a). It was also observed that for a given feed concentration, the drain concentration is fixed at a fixed volume of air delivered per unit volume of feed treated, as can be seen from Table (VI-1b).

(ii) Effect of Residence Time by Varying the Liquid Level and Feed Rate

It was found that for a particular gas rate, the ratio of drain to feed rate in a column increased with an increase in the liquid level. But for a 2.5 inch diameter column the ratio B/L did not change for a change in liquid level from 8.96 to 14.0 inches at a feed rate of 75 cc/min. Further increase in liquid level to 36.0 inches resulted in an increase in B/L . For example, at a feed rate of 25 cc/min. and for a gas rate of 300 cc/min., B/L increased from 0.588 at a liquid level of 8.96 inches to 0.648 at a liquid level of 14.0 inches. Further increase in the liquid level to 36.0 inches at the same gas and feed rates, increased B/L to 0.900. But at a feed rate of 75 cc/min., and for a gas rate of 250 cc/min., B/L remained constant at 0.915 for a change in liquid level from 8.96 to 14.0 inches. A further increase in liquid level to 36.0 inches at similar condition resulted in an increase in B/L to 0.970.

The changes in overhead concentration with the change in liquid level from 8.96 to 14.0 inches were negligible, whereas for a further increase in the liquid level to 36.0 inches resulted in a sharp increase

TABLE (VI-1a)

Effect of Feed Rate on Drain Rate and Drain
Concentration with a Constant Liquid Level of 14.0 inches

Column Diameter (inches)	Gas Rate (cc/min)	Feed Rate (cc/min)					
		25		50		75	
		B/L	x_B (gm/l)	B/L	x_B (gm/l)	B/L	x_B (gm/l)
2.0	250	0.752	0.074	0.880	0.093	0.915	0.113
	400	0.212	0.055	0.580	0.082	0.676	0.103
2.5	250	0.786	0.061	0.890	0.091	0.918	0.112
	400	0.409	0.043	0.837	0.080	0.862	0.097
4.0	1500	0.875	0.033	0.810	0.064	0.045	0.073
	2000	0.799	0.032	0.800	0.045	0.804	0.067
6.0	1500	-	-	0.973	0.063	0.995	0.072
	200	-	-	0.940	0.055	0.970	0.066

TABLE (VI-1b)

Effect of G'/L on Stripping Ratio

Diameter of the Column = 2.5 in.

Liquid Level = 14.0 in.

G'/L	x_B/x_L
0	1.00
4	0.68
8	0.48
12	0.35
14	0.31

in the overhead concentration. Some typical results are shown in Table (VI-2).

For a given drain to feed rate ratio, the stripping ratio decreased with an increase in the liquid height for feed rates of 50 and 75 cc/min. For example, for a 2.5 inch diameter column at a feed rate of 50 cc/min. and for B/L equal to 0.70, the stripping ratio decreased from 0.535 at the liquid levels of 8.96 and 14.0 inches to 0.450 at a liquid level of 36.0 inches. But under similar operating conditions and for a feed rate of 25 cc/min., the stripping ratio remained constant at 0.385 for all liquid levels in the column.

b. Effect of Column Diameter with Constant Volume of Liquid in all the Columns

For the same amount of solution in the columns, the drain rate increased with increasing diameter of the column, whereas the drain concentration was independent of the diameter of the column. At a gas rate of 1000 cc/min. and for a feed rate of 25 cc/min., B/L increased from 0.355 to 0.905 with an increase in column diameter from 2.5 inches to 14.0 inches, whereas, under similar operating conditions, the drain concentration to feed concentration ratio changed by a very small amount, i.e., from 0.270 for a 2.5 inch diameter column to 0.255 for a 4.0 inch diameter column.

c. Effect of Diffuser Diameter

The effect of diffuser diameter on the drain rate, studied with the 4.0 and 6.0 inch diameter columns was more pronounced for the 4.0 inch

TABLE (VI-2)

Effect of Liquid Level on Drain Rate and Overhead Concentration

Column Diameter = 2.5 in.

Feed Rate = 25 cc/min.

Gas Rate (cc/min)	Liquid Level (inches)					
	8.96		14.0		36.0	
	B/L	y_F (gm/l)	B/L	y_F (gm/l)	B/L	y_F (gm/l)
250	0.670	0.370	0.755	0.370	0.920	0.890
300	0.530	0.320	0.650	0.320	0.900	0.750
350	0.398	0.250	0.550	0.260	0.870	0.650

TABLE (VI-3)

Effect of Diffuser Diameter on Drain Rate and Overhead Concentration

Feed Rate = 50 cc/min.

Liquid Level = 14.0 in.

Column Diameter (inches)	Gas Rate (cc/min)	Diffuser Diameter (inches)			
		2.50		1.25	
		B/L	y_F (gm/l)	B/L	y_F (gm/l)
4.0	1000	0.880	1.130	0.900	1.130
	2000	0.825	0.700	0.850	0.790
6.0	2000	0.905	1.320	0.940	1.720
	3000	0.845	0.840	0.890	0.960

diameter column than for the 6.0 inch diameter column. For example, at a feed rate of 50 cc/min and a gas rate of 2000 cc/min., B/L decreased from 0.798 with a diffuser diameter of 1.25 inches to 0.465 with a 2.5 inch diameter diffuser. Under similar operating conditions for a 6.0 inch column, B/L decreased from 0.940 to 0.900 for an increase in diffuser diameter from 1.25 inches to 2.5 inches.

The overhead concentration was also affected by the changes in the diffuser diameter. For the 4.0 inch diameter column, at a feed rate of 50 cc/min., the overhead concentration was not affected by the diffuser diameter up to a gas rate of 1000 cc/min., but decreased with an increase in diffuser diameter for higher gas rates. But for a 6.0 inch diameter column, the overhead concentration decreased with the increase in diffuser diameter at all gas rates. At a gas rate of 2500 cc/min. and for a feed rate of 50 cc/min., an increase in diffuser diameter from 1.25 inches to 2.5 inches resulted in a decrease in y_F from 0.450 (gm/l) to 0.220 (gm/l) with a 4.0 inch diameter column and from 1.230 (gm/l) to 0.965 (gm/l) with a 6.0 inch diameter column. Table (VI-3) gives some of the changes in B/L and y_F with changes in diffuser diameter.

d. Effect of Diffuser Mean Pore Size

At constant gas and feed rates, the increase in mean pore size of the diffuser increased the drain rate by a large amount. For example, at a gas rate of 2000 cc/min., for a 4.0 inch diameter column with a feed rate of 50 cc/min., B/L was 0.50, 0.845 and 0.945 for diffusers with pore size ranges of 20 - 25 μ , 25 - 50 μ , and 50 - 130 μ respectively. The overhead concentration also registered an increase with increasing pore size

of the diffuser. The resulting concentrations were 0.25, 0.58 and 1.59 (gm/l) for diffusers with pore size ranges of 20 - 25 μ , 25 - 50 μ and 50 - 130 μ , respectively. Table VI-4 shows few of the changes in B/L and y_F with changes in diffuser pore sizes.

e. Ideal Foam Model

Equations proposed to predict the performance of a continuous pool fed foam separation column based on an ideal foam model concept were not satisfactory for representing the results of this study. This was due to the excessive foam breakage which resulted in excessive internal reflux.

2. Kinetic Approach

An attempt was made to equate the continuous foam separation column to a backmix reactor and the effects of feed rate, liquid height, diameter of the column and mean pore size of the diffuser on the kinetic rate of foam separation were studied. It was found that for a constant drain concentration, the rate of separation

- (i) increased with the decrease in the diameter of the column for a constant liquid level.
- (ii) increased with the feed rate for the same column.
- (iii) increased with the decrease in the liquid height for the same column.
- (iv) was independent of the diffuser mean pore size.

For a constant liquid level of 14.0 inches above the diffuser, it was found that the rate of separation could be represented by the following equation:

$$r = 0.14 \times 10^{-2} \frac{L^{1.4}}{D_C^{2.5}} (5.64 \times 10^{-4} - x_B)$$

It can be concluded that the kinetic approach of representing the foam separation data is feasible at least for the present system.

3. Properties of Dynamic Foam Columns

The correlation presented by Rubin et. al. (61) for foam ratio in terms of experimental variables was not found satisfactory for application to the EHDA-Br-water system.

TABLE (VI-4)

Effect of Diffuser Pore Size on Drain Rate
and Overhead Concentration

Column Diameter = 4.0 in.

Feed Rate = 50 cc/min.

Gas Rate (cc/min)	Diffuser Pore Size					
	20 - 25 μ		25 - 50 μ		50 - 130 μ	
	B/L	y_F (gm/l)	B/L	y_F (gm/l)	B/L	y_F (gm/l)
1500	0.715	0.390	0.905	1.000	0.965	2.030
2000	0.505	0.270	0.840	0.670	0.940	1.550

NOMENCLATURE

a_i	Activity of the i^{th} component.
a_B	Activity of the solute.
a'	Interstream area per unit volume of foam, (cm^2/cm^3).
A	Interfacial area per unit volume of surface layer, (cm^2/cm^3).
A_i	Interstream area, (cm^2).
A_B	Surface area of each of the solute molecules, (cm^2).
B	Bottoms (or drain or raffinate) flow rate, (cm^3/min).
C_A	Concentration of species A in the reactor at time t, (gm.mole/litre).
C_{AO}	Concentration of the reactant in the feed, (gm.mole/litre).
$\bar{d}$	Average bubble diameter, (cm).
d'	Orifice diameter, (cm).
D	Bubble diameter, (cm).
D_c	Column diameter, (inches, or cm).
D'	Rate of falling liquid stream, (cm^3/min).
f	Foam ratio (volume fraction of liquid in the foam), dimensionless.
f_{PB}	Fractional cross-section available for liquid flow.
F	Collapsed foam (foamate) rate, (cm^3/min).
g	Acceleration of gravity.
G	Volumetric rate of foam, (cm^3/min).
G'	Gas flow rate, (cm^3/min).
k	Constant.
k_1	$1/AB$
k'_1	Intercept of the rate equation.
k'_2	Slope of the rate equation.

k_d	Mass transfer coefficient in falling liquid stream, (gm/(cm ²)(min)(conc)).
k_r	Mass transfer coefficient in rising liquid stream, (gm/(cm ²)(min)(conc)).
K	f/f_{PB} .
L	Feed rate, (cm ³ /min).
n	Constant.
N	Mass transfer rate, (gm/min).
r	Rate of separation, (gm.mole/litre-min).
r_A	Reaction rate, (gm.mole/litre-min).
R	Universal gas constant.
R'	Rate of rising liquid stream, (cm ³ /min).
s	Cross-section of foam column, (cm ²).
S	Volumetric surface layer rate, (cm ³ /min).
t	Time, (min).
T	Absolute temperature, (°K).
u_f	Foam velocity, (cm/sec).
x	Concentration of surfactant in falling liquid stream, (weight percent).
x_B	Concentration of surfactant in bottoms, (gm/litre or gm.mole/litre where indicated).
x_i	Interfacial concentration of surfactant in falling liquid stream, (weight percent).
x_L	Concentration of surfactant in feed, (gm/litre).
x_A	Fractional conversion.
y	Concentration of surfactant in rising liquid stream, (weight percent).

y_F	Concentration of surfactant in the foamate, (gm/litre, or gm.mole/litre where indicated).
y_i	Interfacial concentration of surfactant in rising liquid stream, (weight percent).
y_s	Concentration of surfactant in the surface layer at equilibrium, (gm/cm ³).
Z	Foam column height, (cm).

Greek Letters

μ_i	Chemical potential of i^{th} species.
μ°	Standard chemical potential of the species.
ϕ	Function of variables.
γ	Surface tension of the solution.
Γ	Surface excess of surfactant, (gm/cm ²).
Γ_B	Surface excess of the solute.
Γ_i	Surface excess of i^{th} species.
τ	Liquid residence time, (minutes).
ρ_l	Density of the liquid.
ρ_g	Density of the gas.

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APPENDIX A
TABULATION OF DATA

TABULATION OF DATA

TABLE (A-1a)

Effect of Residence Time on Separation by Varying the Feed Rate

Diameter of the Column = 2.0 in. Diffuser Used = Brass - D1
 Liquid Level = 14.0 in. Diffuser Diameter = 1.25 in.
 Foam Column Height = 53.5 in. Diffuser Pore Size = 20 - 25 μ

i) Feed Rate = 25 cc/min.

Residence Time = 28.84 min.

- (A-1) -

Run No.	G^i (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	150	24.30	0.70	0.110	1.921	0.972	0.733
2	200	23.00	2.00	0.096	0.770	0.920	0.640
3	250	18.80	6.20	0.074	0.380	0.752	0.493
4	300	14.40	10.60	0.070	0.259	0.576	0.467
5	350	8.70	16.30	0.063	0.197	0.348	0.420
6	400	5.30	19.70	0.055	0.175	0.212	0.367

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	12.806	4.617	1.345	0.642	0.359	16.05	9.07
2	5.133	2.208	1.540	0.574	0.411	14.75	10.28
3	2.533	1.391	2.360	0.371	0.630	9.26	15.10
4	1.726	1.008	2.745	0.279	0.733	6.96	18.30
5	1.313	0.584	3.202	0.146	0.855	3.65	21.40
6	1.166	0.292	3.458	0.078	0.923	1.95	23.05

TABLE (A-1a) (Continued)

ii) Feed Rate = 50 cc/min.		Residence Time = 14.42 min.				
Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x _B (gm/l)	y _F (gm/l)	B/L
						x _B /x _L
1	150	49.00	1.00	0.115	1.860	0.980
2	200	47.50	2.50	0.104	1.025	0.950
3	250	44.00	6.00	0.093	0.568	0.880
4	300	40.42	9.58	0.074	0.472	0.808
5	325	38.00	12.00	0.069	0.407	0.760
6	350	35.10	14.10	0.064	0.350	0.702
7*	500	16.12	33.88	0.076	0.185	0.322

Run No.	y _F /x _L	Bx _B x 10 ³ (gm/min)	Fy _F x 10 ³ (gm/min)	Bx _B / Lx _L	Fy _F / Lx _L	Bx _B / x _L (cc/min)	Fy _F / x _L (cc/min)
1	12.400	5.635	1.86	0.753	0.248	37.60	12.40
2	6.833	4.940	2.56	0.658	0.341	32.90	17.10
3	3.786	4.092	3.41	0.545	0.454	27.30	22.70
4	3.146	2.991	4.56	0.397	0.609	19.85	30.50
5	2.713	2.622	4.88	0.349	0.651	17.45	32.55
6	2.333	2.246	5.22	0.304	0.697	15.20	34.80
7*	1.233	1.238	6.262	0.165	0.836	8.24	41.75

* Temperature for this run was low compared with the other runs.

TABLE (A-1a) (Continued)

iii) Feed Rate = 75 cc/min. Residence Time = 9.61 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	150	74.30	0.70	0.119	3.430	0.990	0.793
2	200	72.00	3.00	0.123	0.800	0.960	0.820
3	250	65.60	9.40	0.113	0.408	0.875	0.753
4	300	63.88	11.12	0.107	0.394	0.852	0.713
5	350	58.65	16.35	0.109	0.296	0.783	0.727
6	400	50.75	24.25	0.103	0.228	0.676	0.687
7	450	51.80	23.20	0.103	0.254	0.691	0.686
8	500	45.50	29.50	0.101	0.226	0.606	0.673

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	22.866	8.842	2.40	0.785	0.214	59.00	16.00
2	5.333	8.856	2.40	0.786	0.217	58.70	16.30
3	2.720	7.413	3.84	0.659	0.341	49.40	25.60
4	2.626	6.835	4.41	0.608	0.392	45.60	29.40
5	1.973	6.393	4.85	0.569	0.431	42.65	32.35
6	1.520	5.227	5.52	0.509	0.491	38.10	36.90
7	1.693	5.335	5.91	0.474	0.526	35.60	39.40
8	1.506	4.595	6.65	0.409	0.591	30.60	44.40

TABLE (A-1b)

Effect of Residence Time on Separation by Varying the Feed Rate

Diameter of the Column = 2.5 in. Diffuser Used = Brass - D1
 Liquid Level = 14.0 in. Diffuser Diameter = 1.25 in.
 Foam Column Height = 53.5 in. Diffuser Pore Size = 20 - 25 μ

i) Feed Rate = 25 cc/min. Residence Time = 45.06 min.

Run No.	G^i (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	150	22.36	2.64	0.086	0.689	0.894	0.576
2	200	20.48	4.52	0.081	0.460	0.819	0.544
3	250	19.66	5.34	0.061	0.478	0.786	0.405
4	300	16.21	8.79	0.056	0.323	0.648	0.373
5	350	14.24	10.76	0.050	0.283	0.570	0.331
6	400	10.23	14.77	0.043	0.224	0.409	0.288
7	450	7.06	17.94	0.038	0.194	0.282	0.256

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	4.593	1.932	1.818	0.515	0.485	12.879	12.119
2	3.066	1.671	2.079	0.446	0.554	11.141	13.858
3	3.186	1.195	2.555	0.319	0.681	7.969	17.031
4	2.153	0.908	2.842	0.242	0.758	6.051	18.945
5	1.886	0.706	3.043	0.188	0.811	4.709	20.286
6	1.493	0.442	3.308	0.118	0.882	2.946	22.056
7	1.293	0.271	3.478	0.072	0.928	1.807	23.190

TABLE (A-1b) (Continued)

ii) Feed Rate = 50 cc/min. Residence Time = 22.53 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	150	48.8	1.20	0.108	1.850	0.975	0.720
2	200	45.5	4.50	0.100	0.656	0.910	0.667
3	250	44.5	5.50	0.091	0.627	0.890	0.607
4	275	43.0	7.00	0.096	0.479	0.860	0.643
5	300	41.9	8.10	0.091	0.454	0.837	0.607
6	350	39.8	10.20	0.088	0.392	0.796	0.587
7	375	36.9	13.10	0.087	0.322	0.738	0.583
8	400	33.6	16.40	0.080	0.293	0.672	0.533
9	450	29.7	20.30	0.073	0.262	0.594	0.487
10	500	28.0	22.00	0.074	0.246	0.560	0.493

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	12.333	5.270	2.22	0.704	0.296	35.20	14.80
2	4.373	4.550	2.95	0.616	0.384	30.80	19.20
3	4.180	4.049	3.45	0.540	0.460	27.00	23.00
4	3.193	4.149	3.35	0.551	0.449	27.55	22.45
5	3.026	3.813	3.68	0.508	0.491	25.50	24.50
6	2.613	3.502	4.00	0.466	0.534	23.30	26.70
7	2.146	3.229	4.22	0.438	0.562	21.52	28.10
8	1.953	2.688	4.81	0.358	0.642	17.90	32.10
9	1.746	2.168	5.32	0.290	0.710	14.50	35.50
10	1.640	2.072	5.41	0.277	0.723	13.85	36.15

TABLE (A-1b) (Continued)

iii) Feed Rate = 75 cc/min.		Residence Time = 15.02 min.				
Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L
						x_B/x_L
1	150	73.68	1.32	0.120	1.824	0.984
2	200	72.17	2.83	0.114	1.058	0.962
3	250	68.94	6.06	0.112	0.582	0.918
4	300	64.73	10.27	0.107	0.420	0.862
5	350	60.59	14.41	0.104	0.343	0.807
6	400	54.20	20.80	0.098	0.286	0.724
7	450	48.80	26.20	0.094	0.254	0.651
8	500	41.53	33.47	0.087	0.228	0.554
9	550	41.56	33.44	0.086	0.229	0.554
10	600	33.38	41.62	0.084	0.202	0.444

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	12.160	8.842	2.408	0.786	0.214	58.944	16.055
2	7.053	8.256	2.993	0.734	0.266	55.041	19.957
3	3.880	7.721	3.528	0.686	0.314	51.475	23.520
4	2.800	6.939	4.310	0.617	0.383	46.260	28.735
5	2.286	6.301	4.948	0.560	0.440	42.009	32.989
6	1.906	5.290	5.959	0.470	0.530	35.266	39.728
7	1.693	4.587	6.663	0.408	0.592	30.581	44.417
8	1.520	3.621	7.627	0.322	0.678	24.144	50.847
9	1.526	3.574	7.676	0.318	0.682	23.823	51.173
10	1.346	2.831	8.415	0.252	0.748	18.870	56.103

TABLE (A-1c)

Effect of Residence Time on Separation by Varying the Feed Rate

Diameter of the Column = 4.0 in. Diffuser Used = Brass - D1
 Liquid Level = 14.0 in. Diffuser Diameter = 1.25 in.
 Foam Column Height = 53.5 in. Diffuser Pore Size = 20 - 25μ

i) Feed Rate = 25 cc/min. Residence Time = 115.36 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	600	24.10	0.90	0.045	2.965	0.965	0.300
2	800	23.62	1.38	0.045	1.945	0.944	0.300
3	1000	22.70	2.30	0.040	1.235	0.909	0.267
4	1200	21.96	3.04	0.032	1.002	0.878	0.213
5	1600	20.70	4.30	0.032	0.719	0.828	0.213
6	2000	19.99	5.01	0.032	0.622	0.799	0.213

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	19.766	1.084	2.668	0.289	0.712	7.24	17.80
2	12.966	1.063	2.680	0.283	0.715	7.09	17.85
3	8.233	0.908	2.840	0.242	0.758	6.06	18.94
4	6.680	0.703	3.042	0.187	0.812	4.69	20.30
5	4.793	0.662	3.090	0.177	0.824	4.42	20.60
6	4.146	0.640	3.110	0.170	0.829	4.26	20.73

TABLE (A-1c) (Continued)

ii) Feed Rate = 50 cc/min. Residence Time = 57.68 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	600	48.90	1.10	0.075	3.480	0.978	0.500
2	800	47.75	2.25	0.074	1.760	0.955	0.493
3	1000	45.70	4.30	0.064	1.064	0.914	0.427
4	1200	43.50	6.50	0.050	0.819	0.870	0.333
5	1600	42.00	8.00	0.051	0.669	0.840	0.340
6	2000	39.90	10.10	0.045	0.564	0.798	0.300
7	3000	37.60	12.40	0.040	0.483	0.752	0.267

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	23.200	3.667	3.828	0.488	0.510	24.446	25.520
2	11.733	3.533	3.960	0.471	0.528	23.553	26.400
3	7.093	2.924	4.575	0.389	0.610	19.493	30.500
4	5.460	2.175	5.323	0.290	0.709	14.500	35.486
5	4.460	2.142	5.352	0.285	0.713	14.280	35.680
6	3.760	1.795	5.696	0.239	0.759	11.966	37.973
7	3.220	1.504	5.989	0.200	0.798	10.026	39.926

TABLE (A-1c) (Continued)

iii) Feed Rate = 75 cc/min.

Residence Time = 38.45 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x _B (gm/l)	y _F (gm/l)	B/L
1	600	74.00	1.00	0.096	4.140	0.986
2	800	71.75	3.25	0.085	1.589	0.956
3	1000	69.70	5.30	0.083	1.031	0.929
4	1200	67.90	7.10	0.077	0.849	0.905
5	1600	65.20	9.80	0.075	0.649	0.870
6	2000	60.30	14.70	0.067	0.486	0.804
7	2500	55.94	19.06	0.064	0.403	0.744
8	3000	55.60	19.40	0.064	0.397	0.741
9	3500	54.60	20.40	0.064	0.380	0.728

Run No.	y _F /x _L	Bx _B × 10 ³ (gm/min)	Fy _F × 10 ³ (gm/min)	Bx _B / Lx _L	Fy _F / Lx _L	Bx _B / x _L (cc/min)
1	27.60	7.104	4.14	0.632	0.368	47.40
2	10.593	6.099	5.16	0.541	0.459	40.60
3	6.873	5.785	5.47	0.513	0.487	38.50
4	5.660	5.228	6.02	0.465	0.536	34.90
5	4.326	4.890	6.36	0.436	0.564	32.70
6	3.240	4.040	7.21	0.359	0.641	26.90
7	2.686	3.580	7.67	0.318	0.682	23.85
8	2.646	3.558	7.69	0.316	0.683	23.70
9	2.533	3.494	7.76	0.310	0.690	23.30

TABLE (A-1d)

Effect of Residence Time on Separation by Varying the Feed Rate

Diameter of the Column = 6.0 in. Diffuser Used = Brass - D1
 Liquid Level = 14.0 in. Diffuser Diameter = 1.25 in.
 Foam Column Height = 53.5 in. Diffuser Pore Size = 20 - 25 μ

i) Feed Rate = 50 cc/min. Residence Time = 129.68 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	1500	49.51	0.49	0.064	8.839	0.990	0.427
2	1800	48.65	1.35	0.063	3.278	0.973	0.421
3	2000	47.02	2.98	0.061	1.557	0.940	0.405
4	2500	45.90	4.10	0.053	1.238	0.918	0.352
5	3000	44.90	5.10	0.042	0.898	0.898	0.287
6	4000	43.54	6.46	0.039	0.897	0.871	0.261

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	58.926	3.168	4.331	0.422	0.577	21.120	28.873
2	21.853	3.064	4.425	0.408	0.590	20.426	29.500
3	10.380	2.868	4.639	0.382	0.618	19.120	30.926
4	8.253	2.432	5.075	0.324	0.676	16.213	33.833
5	5.986	1.885	4.579	0.251	0.610	12.566	30.526
6	5.980	1.698	5.794	0.226	0.772	11.320	38.626

TABLE (A-1d) (Continued)

ii) Feed Rate = 75 cc/min. Residence Time = 89.52 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x _B (gm/l)	y _F (gm/l)	B/L	x _B /x _L
1	1800	74.68	0.32	0.080	16.486	0.996	0.533
2	2000	73.41	1.59	0.077	3.393	0.979	0.517
3	2500	73.08	1.92	0.075	2.997	0.974	0.501
4	2700	72.67	2.33	0.070	2.633	0.969	0.469
5	3000	72.53	2.47	0.065	2.638	0.967	0.437
6	3500	71.71	3.29	0.063	2.042	0.956	0.421
7	4000	70.62	4.38	0.059	1.614	0.942	0.395

Run No.	y _F /x _L	Bx _B x 10 ³ (gm/min)	Fy _F x 10 ³ (gm/min)	Bx _B / Lx _L	Fy _F / Lx _L	Bx _B / x _L (cc/min)	Fy _F / x _L (cc/min)
1	109.906	5.974	5.275	0.531	0.468	39.826	35.166
2	22.620	5.652	5.394	0.502	0.479	37.680	35.960
3	19.980	5.481	5.754	0.487	0.511	36.540	38.360
4	17.553	5.086	6.134	0.452	0.545	33.906	40.893
5	17.520	4.714	6.491	0.419	0.576	31.426	43.273
6	13.613	4.517	6.718	0.401	0.597	30.113	44.786
7	10.760	4.166	7.069	0.370	0.628	27.773	47.126

TABLE (A-2a)

Effect of Residence Time on Separation by Varying the Liquid Level and Feed Rate

Diameter of the Column = 2.0 in. Diffuser Used = Brass - D1
 Liquid Level = 56.0 in. Diffuser Diameter = 1.25 in.
 Foam Column Height = 53.5 in. Diffuser Pore Size = 20 - 25 μ

i) Feed Rate = 25 cc/min. Residence Time = 115.36 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	150	23.75	1.25	0.093	1.237	0.950	0.619
2	200	22.36	2.64	0.078	0.756	0.894	0.523
3	250	18.97	6.03	0.073	0.392	0.759	0.485
4	300	15.50	9.50	0.066	0.286	0.620	0.443
5	350	13.00	12.00	0.060	0.247	0.520	0.400
6	400	10.96	14.04	0.056	0.225	0.438	0.373

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	8.246	2.208	1.546	0.588	0.412	14.720	10.306
2	5.040	1.744	1.995	0.465	0.532	11.626	13.300
3	2.620	1.384	2.369	0.369	0.631	9.226	15.793
4	1.906	1.023	2.717	0.272	0.724	6.820	18.113
5	1.646	0.780	2.964	0.208	0.790	5.200	19.760
6	1.500	0.613	3.159	0.163	0.842	4.086	21.060

TABLE (A-2a) (Continued)

ii) Feed Rate = 50 cc/min. Residence Time = 57.68 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	250	45.49	4.51	0.090	0.895	0.910	0.603
2	300	44.43	5.57	0.087	0.651	0.889	0.581
3	350	44.01	5.59	0.086	0.623	0.880	0.571
4	400	42.01	7.99	0.085	0.493	0.840	0.565
5	450	40.46	9.54	0.083	0.433	0.809	0.555
6	500	39.51	10.49	0.081	0.409	0.790	0.541
7	600	36.50	13.50	0.078	0.343	0.730	0.523

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	5.966	4.094	4.036	0.545	0.538	27.293	26.906
2	4.340	3.865	3.626	0.515	0.483	25.766	24.173
3	4.153	3.784	3.482	0.504	0.464	25.226	23.213
4	3.286	3.570	3.939	0.476	0.525	23.800	26.260
5	2.886	3.358	4.130	0.447	0.550	22.386	27.533
6	2.726	3.200	4.290	0.426	0.572	21.333	28.600
7	2.286	2.847	4.630	0.379	0.617	18.980	30.866

TABLE (A-2a) (Continued)

iii) Feed Rate = 75 cc/min. Residence Time = 38.45 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	200	41.99	3.01	0.118	0.906	0.960	0.789
2	300	64.20	10.80	0.107	0.404	0.856	0.715
3	350	61.48	13.52	0.102	0.366	0.820	0.683
4	400	57.29	17.71	0.098	0.319	0.764	0.651
5	450	51.97	23.03	0.094	0.277	0.693	0.624
6	500	47.18	27.82	0.091	0.250	0.629	0.608

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	6.040	8.494	2.727	0.755	0.242	56.626	18.180
2	2.693	6.869	4.363	0.610	0.387	45.793	29.086
3	2.440	6.270	4.948	0.557	0.439	41.800	32.986
4	2.126	5.614	5.649	0.499	0.502	37.426	37.660
5	1.846	4.885	6.379	0.434	0.567	32.566	42.526
6	1.666	4.293	6.955	0.381	0.618	28.620	46.366

TABLE (A-2b)

Effect of Residence Time on Separation by Varying the Liquid Level and Feed Rate

Diameter of the Column = 2.50 in. Diffuser Used = Brass - D1
 Liquid Level = 8.96 in. Diffuser Diameter = 1.25 in.
 Foam Column Height = 53.5 in. Diffuser Pore Size = 20 - 25μ

i) Feed Rate = 25 cc/min. Residence Time = 28.84 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	150	22.83	2.17	0.088	0.802	0.914	0.587
2	200	19.40	5.60	0.067	0.437	0.776	0.448
3	250	15.83	9.17	0.056	0.312	0.634	0.373
4	300	14.62	10.37	0.048	0.294	0.588	0.320
5	350	9.86	15.14	0.043	0.219	0.395	0.288
6	400	5.66	19.34	0.040	0.182	0.227	0.267

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	5.346	2.009	1.740	0.535	0.464	13.393	11.600
2	2.913	1.299	2.447	0.346	0.652	8.660	16.313
3	2.080	0.886	2.861	0.236	0.762	5.906	19.073
4	1.960	0.701	3.048	0.186	0.812	4.673	20.320
5	1.460	0.423	3.315	0.112	0.884	2.820	22.100
6	1.213	0.226	3.519	0.060	0.938	1.506	23.460

TABLE (A-2b) (Continued)

ii) Feed Rate = 50 cc/min. Residence Time = 14.42 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	150	47.66	2.84	0.110	0.989	0.953	0.736
2	200	43.55	6.45	0.104	0.461	0.871	0.693
3	250	37.67	12.33	0.086	0.344	0.753	0.576
4	300	35.64	14.36	0.080	0.324	0.713	0.533
5	350	31.33	18.67	0.074	0.278	0.627	0.491
6	400	28.24	21.76	0.071	0.252	0.565	0.475
7	450	21.50	28.52	0.069	0.211	0.430	0.459
8	500	18.52	31.48	0.066	0.199	0.370	0.437
9	550	15.13	34.87	0.065	0.187	0.303	0.432

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	6.593	5.262	2.314	0.701	0.308	35.077	15.429
2	3.073	4.529	2.971	0.604	0.396	30.195	19.805
3	2.293	3.255	4.245	0.434	0.566	21.697	28.301
4	2.160	2.851	4.648	0.380	0.620	19.008	30.989
5	1.853	2.306	5.194	0.307	0.692	15.372	34.626
6	1.680	2.011	5.488	0.268	0.732	13.404	36.585
7	1.406	1.479	6.018	0.197	0.802	9.861	40.118
8	1.326	1.215	6.283	0.162	0.838	8.093	41.889
9	1.246	0.980	6.517	0.131	0.869	6.536	43.448

TABLE (A-2b) (Continued)

iii) Feed Rate = 75 cc/min. Residence Time = 9.61 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	150	72.78	2.22	0.119	1.166	0.970	0.793
2	200	70.70	4.30	0.111	0.791	0.943	0.740
3	250	67.70	7.30	0.102	0.591	0.903	0.683
4	300	65.49	9.51	0.105	0.460	0.873	0.700
5	350	63.19	11.81	0.096	0.439	0.842	0.640
6	400	55.02	19.98	0.092	0.310	0.734	0.613
7	450	46.34	28.66	0.090	0.248	0.618	0.597
8	500	44.23	30.77	0.088	0.240	0.590	0.587
9	550	40.05	34.95	0.087	0.222	0.534	0.581
10	600	30.73	44.27	0.084	0.195	0.410	0.562
11	650	24.05	50.95	0.078	0.184	0.321	0.517

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	7.773	8.661	2.589	0.770	0.230	57.739	17.261
2	5.273	7.848	3.402	0.698	0.302	52.320	22.680
3	3.940	6.932	4.314	0.616	0.383	46.216	28.762
4	3.066	6.876	4.373	0.611	0.389	46.850	29.150
5	2.926	6.066	5.183	0.539	0.460	40.440	34.560
6	2.066	5.062	6.188	0.450	0.550	33.745	41.255
7	1.653	4.152	7.096	0.369	0.631	27.680	47.308
8	1.600	3.892	7.357	0.356	0.654	25.948	49.947
9	1.480	3.492	7.755	0.310	0.689	23.282	51.702
10	1.300	2.594	8.655	0.231	0.769	17.291	57.698
11	1.226	1.866	9.380	0.166	0.834	12.441	62.532

TABLE (A-2c)

Effect of Residence Time on Separation by Varying the Liquid Level and Feed Rate

Diameter of the Column = 2.5 in. Diffuser Used = Brass - D1
Liquid Level = 36.0 in. Diffuser Diameter = 1.25 in.
Foam Column Height = 53.5 in. Diffuser Pore Size = 20 - 25 μ
i) Feed Rate = 25 cc/min. Residence Time = 115.36 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	250	22.25	2.75	0.083	0.690	0.890	0.554
2	350	22.12	2.88	0.074	0.737	0.884	0.491
3	500	20.03	4.97	0.066	0.490	0.801	0.437
4	600	16.49	8.51	0.062	0.319	0.659	0.416
5	800	12.71	12.29	0.050	0.254	0.508	0.331
6	1000	8.88	16.12	0.041	0.210	0.355	0.272
7	1400	5.30	19.70	0.037	0.180	0.212	0.245

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	4.600	1.846	1.897	0.492	0.505	12.306	12.646
2	4.913	1.636	2.122	0.436	0.565	10.906	14.146
3	3.266	1.321	2.435	0.352	0.649	8.806	16.233
4	2.126	1.022	2.714	0.272	0.723	6.813	18.093
5	1.693	0.635	3.121	0.169	0.832	4.233	20.806
6	1.400	0.364	3.385	0.097	0.902	2.426	22.566
7	1.200	0.196	3.546	0.052	0.945	1.306	23.640

TABLE (A-2c) (Continued)

ii) Feed Rate = 50 cc/min. Residence Time = 57.68 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	350	47.25	2.75	0.097	1.064	0.945	0.645
2	600	44.41	5.59	0.083	0.681	0.888	0.555
3	800	42.94	7.06	0.075	0.605	0.858	0.501
4	925	38.50	11.50	0.072	0.411	0.770	0.480
5	1000	37.13	12.87	0.070	0.379	0.742	0.469
6	1300	30.03	19.97	0.064	0.279	0.600	0.427
7	1600	25.28	24.72	0.061	0.241	0.505	0.405
8	1800	22.80	27.20	0.056	0.229	0.456	0.373

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	7.093	4.583	2.926	0.611	0.390	30.553	19.506
2	4.540	3.686	3.806	0.491	0.507	24.573	25.373
3	4.033	3.220	4.271	0.429	0.569	21.466	28.473
4	2.740	2.772	4.726	0.369	0.630	18.480	31.506
5	2.526	2.599	4.877	0.346	0.650	17.326	32.513
6	1.860	1.921	5.571	0.256	0.742	12.806	37.140
7	1.606	1.542	5.957	0.205	0.794	10.280	39.713
8	1.526	1.276	6.228	0.170	0.830	8.506	41.520

TABLE (A-2c) (Continued)

iii) Feed Rate = 75 cc/min. Residence Time = 38.45 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	300	72.59	2.41	0.115	1.198	0.968	0.768
2	400	71.27	3.73	0.106	0.998	0.950	0.704
3	600	69.73	5.27	0.102	0.780	0.930	0.683
4	800	66.30	8.70	0.096	0.562	0.884	0.640
5	1000	56.21	18.79	0.087	0.338	0.750	0.581
6	1200	53.10	21.90	0.083	0.312	0.708	0.555
7	1600	35.36	39.64	0.070	0.221	0.471	0.469
8	1800	32.39	42.61	0.067	0.213	0.432	0.448

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	7.986	8.347	2.887	0.741	0.256	55.646	19.246
2	6.653	7.554	3.722	0.671	0.330	50.360	24.813
3	5.200	7.112	4.110	0.632	0.365	47.413	27.400
4	3.746	6.364	4.889	0.565	0.434	42.426	32.593
5	2.253	4.890	6.351	0.434	0.564	32.600	42.340
6	2.080	4.407	6.832	0.391	0.607	29.380	45.546
7	1.473	2.475	8.760	0.220	0.778	16.500	58.400
8	1.420	2.170	9.075	0.253	0.806	14.466	60.500

TABLE (A-3a)

Effect of Diffuser Diameter on Separation

Diameter of the Column = 4.0 in. Diffuser Used = Brass - D2
 Liquid Level = 14.0 in. Diffuser Diameter = 2.5 in.
 Foam Column Height = 53.5 in. Diffuser Pore Size = 20 - 25 μ

i) Feed Rate = 50 cc/min. Residence Time = 57.68 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	600	48.71	1.29	0.086	2.551	0.974	0.576
2	900	47.05	2.95	0.068	1.451	0.912	0.456
3	1500	35.00	15.00	0.048	0.388	0.700	0.320
4	1800	32.70	17.30	0.042	0.354	0.654	0.277
5	2000	23.33	26.67	0.038	0.248	0.467	0.256
6	2500	18.57	31.43	0.034	0.218	0.371	0.229
7	3000	15.24	34.76	0.031	0.202	0.304	0.208

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	17.006	4.189	3.290	0.558	0.438	27.926	21.933
2	9.673	3.199	4.280	0.426	0.570	21.326	28.533
3	2.586	1.680	5.820	0.224	0.776	11.200	38.800
4	2.360	1.373	6.124	0.183	0.816	9.153	40.826
5	1.653	0.886	6.614	0.118	0.881	5.906	44.093
6	1.453	0.631	6.851	0.084	0.913	4.206	45.673
7	1.346	0.472	7.021	0.062	0.936	3.146	46.806

TABLE (A-3a) (Continued)

ii) Feed Rate = 75 cc/min. Residence Time = 38.45 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	600	73.83	1.17	0.098	3.456	0.984	0.651
2	825	71.46	3.54	0.085	1.470	0.952	0.564
3	1000	67.11	7.89	0.069	0.841	0.894	0.459
4	1200	58.09	16.91	0.062	0.451	0.774	0.416
5	1400	55.07	19.93	0.056	0.410	0.734	0.373
6	1600	50.05	24.95	0.052	0.346	0.667	0.347
7	2000	46.35	28.65	0.049	0.313	0.618	0.327

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	23.040	7.235	4.043	0.643	0.359	48.233	26.953
2	9.800	6.074	5.203	0.539	0.462	40.493	34.686
3	5.606	4.630	6.635	0.411	0.589	30.866	44.233
4	3.006	3.601	7.626	0.320	0.677	24.006	50.840
5	2.733	3.083	8.171	0.274	0.726	20.553	54.473
6	2.306	2.602	8.632	0.231	0.767	17.346	57.546
7	2.086	2.271	8.967	0.201	0.797	15.140	59.780

TABLE (A-3b)

Effect of Diffuser Diameter on Separation

Diameter of Column = 6.0 in. Diffuser Used = Brass - D2
 Liquid Level = 14.0 in. Diffuser Diameter = 2.5 in.
 Foam Column Height = 53.5 in. Diffuser Pore Size = 20 - 25 μ

i) Feed Rate = 50 cc/min.Residence Time = 129.68 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	1600	47.96	2.04	0.042	2.698	0.959	0.273
2	2000	45.58	4.42	0.039	1.293	0.911	0.261
3	2500	43.67	6.33	0.032	0.964	0.874	0.213
4	2700	43.01	6.99	0.029	0.894	0.860	0.193
5	3000	42.79	7.21	0.026	0.883	0.856	0.176
6	3500	41.17	8.83	0.024	0.737	0.823	0.160

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	17.986	2.014	5.503	0.268	0.733	13.426	36.686
2	8.620	1.777	5.715	0.236	0.762	11.846	38.100
3	6.426	1.397	6.102	0.186	0.813	9.313	40.680
4	5.960	1.247	6.249	0.166	0.833	8.313	41.660
5	5.886	1.112	6.366	0.148	0.848	7.419	42.440
6	4.913	0.988	6.507	0.131	0.867	6.586	43.380

TABLE (A-3b) (Continued)

ii) Feed Rate = 75 cc/min. Residence Time = 89.52 min.

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	1000	73.82	1.18	0.078	4.630	0.984	0.523
2	1500	73.28	1.72	0.064	3.814	0.977	0.427
3	1600	72.04	2.96	0.058	2.399	0.960	0.384
4	1800	70.31	4.69	0.051	1.631	0.937	0.341
5	2250	68.51	6.49	0.045	1.260	0.913	0.299
6	2700	59.51	15.49	0.042	0.566	0.793	0.277
7	3000	60.19	14.81	0.038	0.603	0.802	0.256

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	30.866	5.757	5.463	0.511	0.485	38.380	36.420
2	25.426	4.689	6.560	0.416	0.583	31.260	43.733
3	15.993	4.178	7.101	0.371	0.631	27.853	47.340
4	10.873	3.585	7.649	0.318	0.679	23.900	50.993
5	8.400	3.082	8.177	0.273	0.726	20.546	54.513
6	3.773	2.499	8.767	0.222	0.779	16.660	58.446
7	4.020	2.287	8.930	0.203	0.793	15.246	59.533

TABLE (A-4)

Effect of Diffuser Pore Size on Separation

Diameter of the Column = 4.0 in. Feed Rate = 50 cc/min.
 Liquid Level = 14.0 in. Residence Time = 57.68 min.
 Foam Column Height = 53.5 in. Diffuser Diameter = 2.5 in.

i) Diffuser Used = Brass - A Diffuser Pore Size = 50 - 130 μ

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x _B (gm/l)	y _F (gm/l)	B/L	x _B /x _L
1	1500	48.12	1.88	0.078	1.983	0.962	0.520
2	2000	47.17	2.83	0.064	1.583	0.943	0.426
3	2400	46.25	3.75	0.057	1.290	0.925	0.380
4	2700	46.00	4.00	0.049	1.305	0.920	0.326
5	3075	45.92	4.08	0.044	1.334	0.918	0.293
6	3450	43.63	6.37	0.040	0.903	0.873	0.266
7	4000	41.00	9.00	0.037	0.666	0.820	0.246

Run No.	y _F /x _L	Bx _B x 10 ³ (gm/min)	Fy _F x 10 ³ (gm/min)	Bx _B / Lx _L	Fy _F / Lx _L	Bx _B / x _L (cc/min)	Fy _F / x _L (cc/min)
1	13.220	3.750	3.727	0.500	0.497	25.022	24.853
2	10.553	3.007	4.481	0.401	0.597	20.094	29.873
3	8.600	2.636	4.836	0.351	0.644	17.575	32.240
4	8.700	2.254	5.218	0.300	0.695	15.026	34.786
5	8.893	2.020	5.443	0.269	0.725	13.466	36.286
6	6.020	1.745	5.755	0.232	0.767	11.633	38.366
7	4.440	1.517	5.990	0.202	0.798	10.113	39.933

TABLE (A-4) (Continued)

ii) Diffuser Used = Brass - B Diffuser Pore Size = 25 - 50 μ

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x _B (gm/l)	y _F (gm/l)	B/L	x _B /x _L
1	800	48.51	1.49	0.087	2.195	0.970	0.580
2	1000	47.22	2.78	0.080	1.339	0.944	0.533
3	1500	45.66	4.34	0.066	1.038	0.913	0.440
4	2000	42.70	7.30	0.056	0.700	0.854	0.373
5	2500	37.00	13.00	0.048	0.440	0.740	0.320
6	3000	35.90	14.10	0.042	0.424	0.718	0.280
7	3500	35.68	14.32	0.039	0.427	0.714	0.260

Run No.	y _F /x _L	Bx _B x 10 ³ (gm/min)	Fy _F x 10 ³ (gm/min)	Bx _B / Lx _L	Fy _F / Lx _L	Bx _B / x _L (cc/min)	Fy _F / x _L (cc/min)
1	14.633	4.220	3.270	0.562	0.436	28.133	21.800
2	8.926	3.777	3.722	0.503	0.496	25.180	24.813
3	6.920	3.013	4.504	0.401	0.600	20.086	30.026
4	4.666	2.391	5.108	0.318	0.681	15.940	34.053
5	2.933	1.776	5.724	0.236	0.763	11.840	38.160
6	2.826	1.507	5.977	0.200	0.796	10.046	39.846
7	2.846	1.391	6.115	0.185	0.815	9.273	40.766

TABLE (A-4) (Continued)

iii) Diffuser Used = Brass - C Diffuser Pore Size = 15 - 25 μ

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	600	47.06	2.94	0.078	1.296	0.941	0.520
2	825	45.42	4.58	0.064	1.003	0.918	0.426
3	1000	44.75	5.25	0.061	0.910	0.895	0.406
4	1200	43.61	6.39	0.056	0.791	0.872	0.373
5	1500	41.15	8.85	0.053	0.602	0.823	0.353
6	2000	37.50	12.50	0.046	0.461	0.750	0.306

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	8.640	3.670	3.810	0.489	0.508	24.466	25.400
2	6.686	2.906	4.593	0.387	0.612	19.373	30.620
3	6.066	2.729	4.779	0.363	0.637	18.193	31.860
4	5.273	2.442	5.058	0.325	0.671	16.280	33.586
5	4.013	2.180	5.327	0.290	0.710	14.533	35.513
6	3.073	1.725	5.760	0.230	0.768	11.500	38.400

TABLE (A-4) (Continued)

iv) Diffuser Used = Brass - D Diffuser Pore Size = 5 - 15 μ

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x _B (gm/l)	y _F (gm/l)	B/L	x _B /x _L
1	450	48.10	1.90	0.106	1.274	0.962	0.706
2	650	45.97	4.03	0.071	1.049	0.919	0.473
3	1000	42.14	7.86	0.065	0.607	0.843	0.433
4	1160	38.00	12.00	0.051	0.463	0.760	0.340
5	1500	32.86	17.14	0.042	0.358	0.657	0.280
6	2000	20.93	29.07	0.034	0.233	0.419	0.226

Run No.	y _F /x _L	Bx _B x 10 ³ (gm/min)	Fy _F x 10 ³ (gm/min)	Bx _B / Lx _L	Fy _F / Lx _L	Bx _B / x _L (cc/min)	Fy _F / x _L (cc/min)
1	8.493	5.098	2.421	0.679	0.322	33.986	16.140
2	6.993	3.263	4.227	0.435	0.563	21.753	28.180
3	4.046	2.739	4.769	0.365	0.635	18.260	31.793
4	3.086	1.938	5.554	0.258	0.740	12.920	37.026
5	2.386	1.380	6.133	0.184	0.817	9.200	40.886
6	1.553	0.711	6.779	0.094	0.903	4.740	45.193

TABLE (A-4) (Continued)

v) Diffuser Used = Stainless Steel Diffuser Pore Size = 20μ

Run No.	G' (cc/min)	B (cc/min)	F (cc/min)	x_B (gm/l)	y_F (gm/l)	B/L	x_B/x_L
1	400	48.20	1.80	0.072	2.238	0.964	0.480
2	600	45.84	4.16	0.061	1.133	0.917	0.406
3	800	39.46	10.54	0.053	0.514	0.789	0.353
4	1000	31.69	18.31	0.046	0.329	0.634	0.306
5	1175	21.83	28.17	0.041	0.235	0.438	0.273

Run No.	y_F/x_L	$Bx_B \times 10^3$ (gm/min)	$Fy_F \times 10^3$ (gm/min)	$\frac{Bx_B}{Lx_L}$	$\frac{Fy_F}{Lx_L}$	$\frac{Bx_B}{x_L}$ (cc/min)	$\frac{Fy_F}{x_L}$ (cc/min)
1	14.920	3.470	4.029	0.462	0.537	23.133	26.860
2	7.553	2.796	4.713	0.372	0.628	18.640	31.420
3	3.426	2.091	5.416	0.278	0.722	13.940	36.106
4	2.193	1.457	6.029	0.194	0.803	9.713	40.193
5	1.566	0.895	6.609	0.119	0.881	5.966	44.060

APPENDIX B

ANALYSIS OF EHDA-Br WITH SODIUM TETRAPHENYLBORON

ANALYSIS OF EHDA-Br WITH SODIUM TETRAPHENYLBORON

Reagents:

Sodium tetrphenylboron, (STPB): (source: Fisher, Cat. No. S-652).

3.42 grams of STPB was dissolved in a litre of distilled water in a volumetric flask. The pH of the solution was adjusted to 9 to 10 with NaOH and the solution was stored in an amber glass bottle.

Buffer Solution, (pH 3.0): Equal volumes of 0.5 M citric acid (96.065 g in one litre of distilled water) and 0.2 M sodium phosphate (53.614 g in one litre of distilled water) were mixed thoroughly and stored in an amber glass bottle.

Methyl orange solution, 0.15% aqueous: 0.75 g of methyl orange crystals were dissolved in 500 ml of distilled water and stored.

Chloroform

Procedure: Solution of the surfactant of known concentration was prepared. 25 ml of this solution was pipetted out into a 125 ml separatory funnel, diluted with 25 ml of distilled water. 5 ml of the buffer solution (pH 3.0) was added only with 7 drops of methyl orange. About 30 ml of chloroform was added to the mixture and it was shaken vigorously. This solution was titrated with STPB solution by adding small amounts, re-stoppering and shaking. The titration was continued until the yellow color in the chloroform layer became completely colorless. This procedure was repeated with other concentrations of surfactant. A plot of ml of STPB

consumed versus g/l of EHDA-Br was prepared.

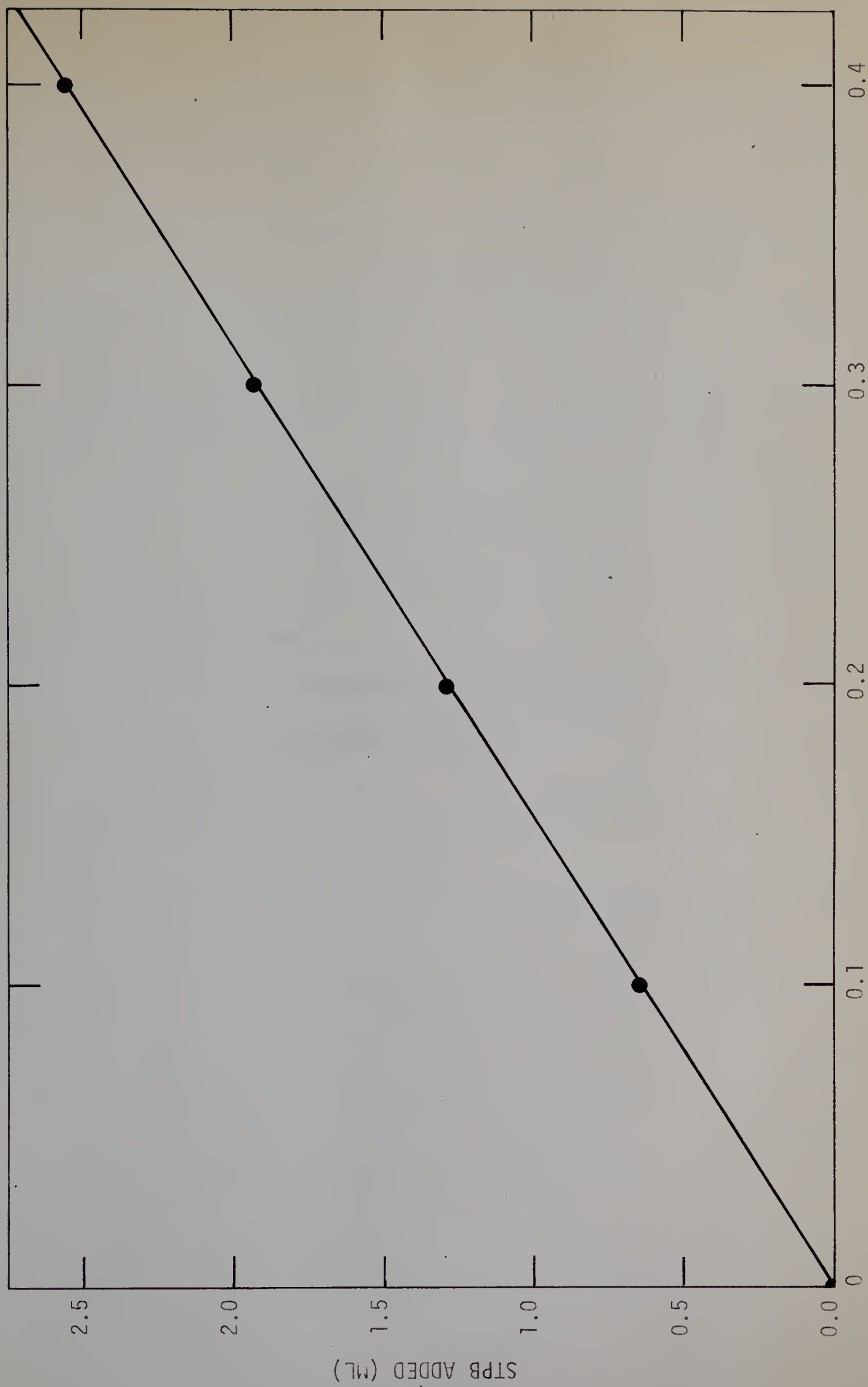
Analysis of bottoms and foamate

The above procedure was repeated with 25 ml of bottoms and foamate solutions. From the amount of STPB consumed, the concentration of EHDA-Br was read off from the calibration curve.

TABLE (B-1)

Data for the Calibration Curve

Concentration of EHDA-Br (g/l)	STPB consumed (ml)
0	0
0.02	0.125
0.10	0.650
0.20	1.300
0.30	1.900
0.40	2.550



CONCENTRATION OF EHDA-Br (gm/L)

FIG. 27 CALIBRATION CURVE FOR ANALYSIS OF EHDA-Br

APPENDIX C
CALCULATED RESULTS

PROGRAM LISTING

NO.	TITLE	PAGE NO.
1.	MAIN LINE PROGRAM READING IN THE DATA	C - 2
2.	SUBROUTINE VIDHYA SUBROUTINE TO GENERATE THE MATRIX FOR LEAST SQUARE SOLUTION	C - 5
3.	SUBROUTINE GAUSS SUBROUTINE TO SOLVE THE MATRIX	C - 7
4.	SUBROUTINE CALC SUBROUTINE TO CALCULATE (G'/L)	C - 9
5.	SUBROUTINE FIRST SUBROUTINE TO CALCULATE THE RATE OF SEPARATION FROM THE DATA AND TO CALCULATE INTERCEPT AND SLOPE OF RATE VS XB STRAIGHT LINE	C - 10
6.	SUBROUTINE SECOND SUBROUTINE TO CALCULATE DECONTAMINATION FACTOR AND SLOPE AND INTERCEPT OF LOG(Df-1) VS LOG(G') STRAIGHT LINE	C - 12
7.	SUBROUTINE STDEVI SUBROUTINE TO CALCULATE STANDARD DEVIATION	C - 13
8.	SUBROUTINE THIRD SUBROUTINE TO CALCULATE SURFACE TENSION CORRESPONDING TO A PARTICULAR XB.	C - 14
9.	SUBROUTINE BUBD SUBROUTINE TO CALCULATE BUBBLE DIAMETER	C - 15
10.	SUBROUTINE CORREL SUBROUTINE TO CALCULATE THE RATE FROM THE CORRELATION	C - 16
11.	SUBROUTINE FOURTH SUBROUTINE TO CALCULATE FOAM RATIO, FOAM VELOCITY, DRAINAGE TIME, F.DSQ, F.DSQ.DC**0.2	C - 18

C CONTROL CARDS

C
C
C
C NOMENCLATURE USED

C XL - THE CONCENTRATION OF SURFACTANT IN FEED-(G/L).

C B - BOTTOMS RATE-(CC/MINUTE).

C YF - CONCENTRATION OF SURFACTANT IN FOAMATE-(G/L).

C XB - CONCENTRATION IN BOTTOMS-(G/L).

C X1 - CONCENTRATION OF SURFACTANT-(G/L).

C ST - SURFACE TENSION OF THE SOLUTION-(DYNES/CMSQ).

C T - RESIDENCE TIME-(MINUTES).

C DC - DIAMETER OF THE COLUMN-(INCHES).

C HT - HEIGHT OF THE LIQUID LEVEL-(INCHES).

C F - FOAMATE RATE-(CC/MINUTE).

C N - NUMBER OF RUNS FOR EACH SET.

C M - ORDER OF THE LEAST SQUARES FIT.

C X AND Y - VALUES OF THE VARIABLES TO BE FITTED.

C KK - INDEX USED TO WRITE THE PAGE NUMBER.

C G - GAS RATE-(CC/MINUTE).

C L - LIQUID FEED RATE-(CC/MINUTE).

C Z - DESCRIPTION OF THE DIFFUSER.

C BRASS - DIAMETER OF THE DIFFUSER-(CM).

C SIGMA - STANDARD DEVIATION.

C JJ - NUMBER OF SETS=29.

C

C

C

C MAIN LINE PROGRAM

C

C

DIMENSION X1(20), ST(20), XB(20), YF(20), G(20),
1F(20), B(20), X(20,5), Y(20), A(10,10), RHS(10,5),
2BD(20), YY(10,10), Z(5,5)

KK=21

DO 101 JJ=1,29

C

C READ IN THE DATA.

C

READ(5,201)(X1(I), I=1,4)

READ(5,202)(ST(I), I=1,4)

READ(5,203)N

READ(5,204)(XB(I), I=1,N)

READ(5,205)(YF(I), I=1,N)

READ(5,206)(G(I), I=1,N)

READ(5,207)L, T, DC, HT

READ(5,208)(F(I), I=1,N)

READ(5,209)(Z(1,I), I=1,3), DP, BRASS

DO 100 J=1,N

B(J)=(FLOAT(L)-F(J))

100 CONTINUE

WRITE(6,300)


```

WRITE(6,301)KK
WRITE(6,480)
IF(KK.NE.21)GO TO 104
WRITE(6,400)
WRITE(6,490)
GO TO 103
104 WRITE(6,401)
103 WRITE(6,302)DC, L
WRITE(6,510) BRASS, (Z(1,I), I=1,3)
WRITE(6,303)T, HT
WRITE(6,304)

C      IF(HT.EQ.14.00.AND.BRASS.EQ.1.25)GO TO 80
      GO TO 90
C      SUBROUTINE TO CALCULATE (G.RATE/L).
80     CALL CALC(G, L, N, XB, DC, HT, T, Z, BRASS, KK)
C
C      SUBROUTINE TO CALCULATE THE RATE OF SEPARATION AND TO
C      OBTAIN SLOPE AND INTERCEPT OF THE RATE VS XB STRAIGHT
C      LINE.
90     CALL FIRST(XB, YF, F, T, DC, HT, L, N, KK, BRASS, Z)
C
C      SUBROUTINE TO CALCULATE THE DECONTAMINATION FACTOR
C      AND TO CORRELATE IT AGAINST GAS RATE.
C
      CALL SECOND(XB, G, N, L, DC, T, HT, KK)
      IF(HT.EQ.14.00.AND.BRASS.EQ.1.25)GO TO 81
      GO TO 91
C      SUBROUTINE TO CALCULATE RATE FROM THE CORRELATION,
C      AND TO CALCULATE PERCENT STANDARD DEVIATION.
81     CALL CORREL(XB,YF,F,L,T,N,DC,HT,T,Z,BRASS,KK)
C
C      SUBROUTINE TO CALCULATE SURFACE TENSION
C
91     CALL THIRD(X1, ST, X, Y)
      NL=N
      N=4
      M=1
C      SUBROUTINE TO GENERATE THE MATRIX.
      CALL VIDHYA(X, Y, A, RHS, N, M )
      MN=M+1
C      SUBROUTINE TO SOLVE THE MATRIX.
      CALL GAUSS(A, RHS, YY, MN)
      N=NL
C      SUBROUTINE TO CALCULATE BUBBLE DIAMETER.
      CALL BUBD(XB, YY, BD, N, DP)
C      SUBROUTINE TO CALCULATE FOAM RATIO, FOAM VELOCITY,
C      DRAINAGE TIME, F.DSQ, F.DSQ.DC**0.2.
      CALL FOURTH(XB, G, BD, DC, F, N, KK, L, T, HT, Z, BRASS
1)      S
      KK=KK+1
101  CONTINUE

```



```
201  FORMAT(4F10.4)
202  FORMAT(4F6.1)
203  FORMAT(10X, I4)
204  FORMAT((8F10.5))
205  FORMAT((8F10.5))
206  FORMAT(11F7.1)
207  FORMAT(10X, I5, 10X, F10.2, 5X, F8.2, 5X, F7.2)
208  FORMAT(12F6.2)
209  FORMAT(3A4, E12.2, F6.2 )
300  FORMAT('1' )
301  FORMAT('0', 40X, 'C - ', I3)
480  FORMAT('-'/////////)
400  FORMAT('0', 37X, 'TABLE - (C-1).' )
490  FORMAT(' ', 20X, 'EFFECT OF (G.RATE/L) ON STRIPPING ',
1'RATIO' )
401  FORMAT('0', 34X, 'TABLE - (C-1).(CONTD)' )
302  FORMAT('0', 14X, 'DIA.OF COLUMN =', F6.2, 'IN.', 17X,
1'FEED RATE =', I5, 'CC/MIN.' )
510  FORMAT(15X, 'DIA.OF DIFFUSER =', F6.2, 'IN.', 15X,
1'DIFFUSER = ', 3A4 )
303  FORMAT(15X, 'RESIDENCE TIME =', F8.2, 'MIN.', 13X,
1'LIQUID LEVEL =', F7.2, 'IN.')
304  FORMAT('-', 33X, 'G.RATE/L', 19X, 'XB/XL' )
STOP
END
```


SUBROUTINE VIDHYA(X, Y, A, RHS, N, M)

THIS SUBROUTINE IS USED TO GENERATE THE MATRIX USING
THE X'S AND Y'S.

A - ELEMENTS OF THE MATRIX GENERATED.

RHS - RIGHT HAND SIDE ELEMENTS OF THE MATRIX.

DIMENSION X(20,5), Y(20), A(10,10), RHS(10,5),
1XX(20,5), XY(20), SUMO(20), SUM(20,5), SUM3(20),
2SUM1(20), B(20,5)

INTEGER NM, NN, MM, MN

CALCULATION OF SUM FO X S

DO 101 J=1,M

SUMO(J)=0.0

DO 100 I=1,N

SUMO(J)=SUMO(J) + X(I,J)

100 CONTINUE

101 CONTINUE

CALCULATION OF SQUARES OF X S

DO 103 J=1,M

SUM1(J)=0.0

DO 102 I=1,N

XX(I,J) = X(I,J)**2

SUM1(J) = SUM1(J) + XX(I,J)

102 CONTINUE

103 CONTINUE

CALCULATION OF SUM OF X1.X2 ETC.

NN=M-1

DO 106 J=1,NN

KK=J+1

DO 105 K=KK,M

SUM(K,J)=0.0

DO 104 I=1,N

B(I,K)= X(I,J)*X(I,K)

SUM(K,J)=SUM(K,J) + B(I,K)

104 CONTINUE

105 CONTINUE

106 CONTINUE

CALCULATION FOR Y S

SUM2=0.0

DO 107 I=1,N

SUM2 = SUM2 + Y(I)

107 CONTINUE


```

C
C   CALCULATION FOR SIGMA X.Y S
C
      DO 109 J=1,M
      SUM3(J)=0.0
      DO 108 I=1,N
      XY(J)=X(I,J)*Y(I)
      SUM3(J) = SUM3(J) + XY(J)
108   CONTINUE
109   CONTINUE
C
C   ASSIGN VALUES FOR THE COEFFICIENTS
C
      A(1,1)= FLCAT(N)
      DO 110 J=1,M
      A(J+1,J+1) = SUM1(J)
110   CONTINUE
      DO 111 J=1,M
      A(J+1,1) = SUM0(J)
111   CONTINUE
      DO 112 J=1,M
      A(1,J+1) = SUM0(J)
112   CONTINUE
      MN=M+1
      DO 114 J=2,M
      LL=J+1
      DO 113 I=LL,MN
      A(J,I)= SUM(I-1, J-1)
113   CONTINUE
114   CONTINUE
      MN=M+1
      DO 116 J=2,M
      LK=J+1
      DO 115 K=LK,MN
      A(K,J)=SUM(K-1,J-1)
115   CONTINUE
116   CONTINUE
C
C   ASSIGNING VALUES FOR RHS
C
      RHS(1,1)=SUM2
      MN=M+1
      DO 117 K=2,MN
      RHS(K,1)=SUM3(K-1)
117   CONTINUE
      RETURN
      END

```



```

SUBROUTINE GAUSS(A, RHS, YY, MN )
C
C THIS SUBROUTINE IS USED TO SOLVE THE GENERATED MATRIX
C BY THE METHOD OF GAUSSIAN ELIMINATION.
C
C YY'S ARE THE SOLUTIONS OF THE MATRIX
C
C DIMENSION A(10,10), RHS(10,5), YY(10,10)
C DIMENSION AA(10,10)
C INTEGER NP
C M=1
C N=MN
C
C SAVE THE ORIGINAL MATRIX
C
C DO 101 I=1,N
C DO 101 J=1,N
C AA(I,J)=A(I,J)
101 CONTINUE
C DO 114 JK=1,M
C
C SHIFTING ROWS TO GET THE MAXIMUM FIRST ELEMENT ON THE T
10P S
C
C NP=N-1
C DO 125 K=1,NP
C D=A(K,K)
C JI=K+1
C DO 104 I=JI,N
C DIFF=ABS(D)-ABS(A(I,K))
C IF(DIFF.GE.C.0) GO TO 104
C D=A(I,K)
C II=I
104 CONTINUE
C IF(D.EQ.A(K,K)) GO TO 119
C DO 117 J=K,N
C C=A(K,J)
C A(K,J)=A(II,J)
C A(II,J)=C
C
C SHIFTING THE RIGHT HAND SIDE ELEMENT TO THE TOP
C
117 CONTINUE
C C=RHS(II,JK)
C RHS(II,JK)=RHS(K,JK)
C RHS(K,JK)=C
C
C MAKING THE FIRST ELEMENT EQUAL TO ZERO.
C
119 H=A(K,K)
C DO 128 J=K,N

```



```

      A(K,J)=A(K,J)/H
128  CONTINUE
      RHS(K,JK)=RHS(K,JK)/H
C
C  START OF ELIMINATION.
C
      DO 122 JJ=JI,N
      RR=A(JJ,K)
      DO 123 I=K,N
      A(JJ,I)=A(JJ,I)-A(K,I)*RR
123  CONTINUE
      RHS(JJ,JK)=RHS(JJ,JK)-RHS(K,JK)*RR
122  CONTINUE
125  CONTINUE
111  YY(N,JK)=RHS(N,JK)/A(N,N)
      NP=N-1
      DO 112 I=1,NP
      K=N-I
      KI=K+1
      SUM=0.0
      DO 118 L=KI,N
      SUM=SUM + A(K,L)*YY(L,JK)
118  CONTINUE
      YY(K,JK)=(RHS(K,JK)-SUM)/A(K,K)
112  CONTINUE
C
C  REGENERATE THE ORIGINAL MATRIX
C
      DO 113 LK=1,N
      DO 113 LL=1,N
      A(LK,LL)=AA(LK,LL)
113  CONTINUE
114  CONTINUE
115  RETURN
      END

```



```
      SUBROUTINE CALC(G, L, N, XB, DC, HT, T, Z, BRASS, KK)
C     SUBROUTINE TO CALCULATE (GAS RATE/L ).
C     GG - GAS RATE/L.
C     XB2 - XB IN G.MOLE/LITRE.
      DIMENSION G(20), XB(20), XB2(20), Z(5,5), GG(20)
      XL=0.15
      DO 100 I=1,N
      GG(I)=G(I)/FLOAT(L)
      XB2(I)=XB(I)/XL
100   CONTINUE
      WRITE(6,306)(GG(I), XB2(I), I=1,N)
306   FORMAT(33X, F8.3, 16X, F10.4 )
      RETURN
      END
```



```

SUBROUTINE FIRST(XB, YF, F, T, DC, HT, L, N, KK, BRASS,
1 Z)

```

```

C
C SUBROUTINE TO CALCULATE THE RATE OF SEPARATION
C FROM THE DATA OBTAINED.
C
C
C R - THE RATE OF SEPARATION-(G.MOLE/LITRE-MINUTE).
C WT - MOLECULAR WEIGHT OF THE SURFACTANT.
C XB1 - SURFACTANT CONCENTRATION IN G.MOLE/LITRE.
C
  DIMENSION XB(20), YF(20), F(20), R(20), X(20,5),
1Y(20), A(10,10), RHS(10,5), YY(10,10), YC(20), DEV(20)
  DIMENSION XB1(20), Z(5,5)
  KJ=11+KK
  WT=378.476
  DO 100 I=1,N
C
C CALCULATION OF RATE OF SEPARATION.
C
  R(I)= ((F(I)*YF(I))/(T*FLOAT(L)*WT))
100 CONTINUE
C
C CALCULATION FOR SLOPE AND INTERCEPT FOR THE STRAIGHT
C LINE OF RATE VS XB.
C
  DO 101 K=1,N
  X(K,1)=XB(K)/WT
  Y(K)=R(K)
101 CONTINUE
  M=1
  CALL VIDHYA(X, Y, A, RHS, N, M)
  MN=M+1
  CALL GAUSS(A, RHS, YY, MN)
  CALL STDEVI(X, Y, YY, N, M, SIGMA, YC)
  DO 102 I=1,N
  XB1(I)=XB(I)/WT
  DEV(I)=R(I)-YC(I)
102 CONTINUE
  WRITE(6,300)
  WRITE(6,301)KJ
  WRITE(6,515)
  IF(KK.NE.21) GO TO 104
  WRITE(6,400)
  WRITE(6,490)
  GO TO 103
104 WRITE(6,401)
103 WRITE(6,302)DC, L
  WRITE(6,510) BRASS, (Z(1,I), I=1,3)
  WRITE(6,303)T, HT
  WRITE(6,201)
  WRITE(6,202)

```



```

WRITE(6,203)(XB1(I),R(I), YC(I), DEV(I), I=1,N)
WRITE(6,500)
WRITE(6,204)(YY(K,1), K=1,MN)
WRITE(6,500)
WRITE(6,205)SIGMA
300 FORMAT('1' )
301 FORMAT('0', 40X, 'C - ', I3)
515 FORMAT('-'//// )
400 FORMAT('0', 37X, 'TABLE - (C-2).' )
490 FORMAT('-',20X,'RATE OF SEPARATION AND DECONTAMINA',
1'TION FACTOR' )
401 FORMAT('0', 34X, 'TABLE - (C-2).(CONTD)' )
302 FORMAT('0',14X,'DIA.OF COLUMN =',F6.2,'IN.',17X,
1'FEED RATE =', I5, 'CC/MIN.' )
510 FORMAT(15X, 'DIA.OF DIFFUSER =',F6.2,'IN.',15X,
1'DIFFUSER =',3A4 )
303 FORMAT(15X, 'RESIDENCE TIME =',F8.2,'MIN.',13X,
1'LIQUID LEVEL =',F7.2,'IN.')
201 FORMAT('-',17X,'XB',12X,'RATE',10X,'RATE(CALULATED)',
16X, 'DIFFERENCE')
202 FORMAT(14X,'(GMOLE/L)',5X,'(G.MOLE/LIT-MIN)',3X,
1'(G.MOLE/LIT-MIN)' )
203 FORMAT(12X,E12.5,3X,E16.8,3X,E16.8,3X,E16.8 )
500 FORMAT(' ', ' ')
204 FORMAT(14X,'CONSTANTS ARE :', 'INTERCEPT =',E16.8,
13X,'SLOPE =',E16.8 )
205 FORMAT(25X, 'THE STANDARD DEVIATION OBTAINED =',E16.8)
RETURN
END

```



```

SUBROUTINE SECOND(XB, G, N, L, DC, T, HT, KK)
C
C SUBROUTINE TO CALCULATE THE DECONTAMINATION FACTOR
C AND TO CORRELATE LOG(D.F-1) VS LOG(G)
C
C
C DF - THE DECONTAMINATION FACTOR.
C
  DIMENSION XB(20), G(20), DF(20), X(20,5), Y(20),
1A(10,10), RHS(10,5), YY(10,10), YC(20), DEV(20)
  XL=0.150
  DO 100 I=1,N
    DF(I)=XL/XB(I)
    Y(I)=ALOG(DF(I)-1.0)
    X(I,1)=ALOG(G(I))
100  CONTINUE
    M=1
    CALL VIDHYA(X, Y, A, RHS, N, M)
    MN=M+1
    CALL GAUSS(A, RHS, YY, MN)
    CALL STDEVI(X, Y, YY, N, M, SIGMA, YC)
    STD=0.0
    DO 101 I=1,N
      YC(I)=EXP(YC(I))
      Y(I)=EXP(Y(I))
      DEV(I)=Y(I)-YC(I)
      STD=STD+DEV(I)**2
101  CONTINUE
    SIGMA=SQRT(STD)/FLOAT(N)
    WRITE(6,304)
    WRITE(6,305)
    WRITE(6,306)(G(I), Y(I), YC(I), DEV(I), I=1,N )
    YY(1,1)=EXP(YY(1,1))
    WRITE(6,500)
    WRITE(6,307)(YY(K,1), K=1,MN)
    WRITE(6,500)
    WRITE(6,308) SIGMA
304  FORMAT('-', 15X, 'GAS RATE', 9X, '(D.F-1)', 13X, '(D.F-1)',
110X, 'DIFFERENCE' )
305  FORMAT(16X, '(CC/MIN)', 26X, '(CALCULATED)' )
306  FORMAT(14X, F10.1, 8X, F8.4, 11X, F8.4, 11X, F8.4 )
500  FORMAT(' ', ' ')
307  FORMAT(14X, 'CONSTANTS ARE:', 'INTERCEPT =', E16.8,
16X, 'SLOPE =', E16.8 )
308  FORMAT(25X, 'THE STANDARD DEVIATION OBTAINED=', E16.8)
  RETURN
  END

```



```

SUBROUTINE STDEVI(X, Y, YY, N, M, SIGMA, YC )
C
C SUBROUTINE TO CALCULATE THE STANDARD DEVIATION AND
C VALUES FOR Y FROM THE CORRELATION.
C
C YC - VALUES OF Y CALCULATED USING THE CORRELATION.
C SIGMA - STANDARD DEVIATION OBTAINED.
C DEV - THE DEVIATION FROM THE CALCULATED VALUE OF Y.
C
  DIMENSION X(20,5), Y(20), YY(10,10), DEV(20), YC(20),
1 YC1(20)
  STD=0.0
  DO 100 K=1,N
    GO TO(101, 102, 103, 104, 105),M
101  YC1(K)=YY(1,1)+YY(2,1)*X(K,1)
    GO TO 106
102  YC1(K)=YY(1,1)+YY(2,1)*X(K,1)+YY(3,1)*X(K,2)
    GO TO 106
103  YC1(K)=YY(1,1)+YY(2,1)*X(K,1)+YY(3,1)*X(K,2)+YY(4,1)*
1 X(K,3)
    GO TO 106
104  YC1(K)=YY(1,1)+YY(2,1)*X(K,1)+YY(3,1)*X(K,2)+YY(4,1)*
1 X(K,3)+YY(5,1)*X(K,4)
    GO TO 106
105  YC1(K)=YY(1,1) + YY(2,1)*X(K,1) + YY(3,1)*X(K,2) +
1 YY(4,1)*X(K,3)+YY(5,1)*X(K,4)+YY(6,1)*X(K,5)
106  YC(K)=YC1(K)
    DEV(K)=YC(K)-Y(K)
    STD=STD+DEV(K)**2
100  CONTINUE
    SIGMA=SQRT(STD)/FLOAT(N)
    RETURN
    END

```



```
      SUBROUTINE THIRD(X1, ST, X, Y)
C
C      SUBROUTINE USED TO CORRELATE SURFACE TENSION WITH
C      CONCENTRATION OF THE SURFACTANT.
C
C      X1 - CONCENTRATION FO THE SURFACTANT-(G/L).
C      ST - SURFACE TENSION OF THE SOLUTION-(DYNES/CMSQ).
C
      DIMENSION X1(15), ST(15), X(15,5), Y(15)
      DO 101 J=1,4
      X(J,1)=ALOG10(X1(J))
      Y(J)=ST(J)
101  CONTINUE
      RETURN
      END
```



```
      SUBROUTINE BUBD(XB, YY, BD, N, DP)
C
C      SUBROUTINE USED TO CALCULATE THE BUBBLE DIAMETER.
C
C      DP - MEAN PORE SIZE OF THE DIFFUSER-(CM).
C      BD - BUBBLE DIAMETER-(CM).
C      STC - SURFACE TENSION CALCULATED FOR A PARTICULAR
C      SURFACTANT CONCENTRATION.
C      AG - ACCELARATION DUE TO GRAVITY.
C      DD - LIQUID DENSITY.
C      DG - GAS DENSITY.
C
      DIMENSION XB(20), YY(10,10), BD(20), STC(20)
      AG=980.7
      DD=1.0
      DG=0.0808/62.4
      DO 101 J=1,N
      STC(J)=YY(1,1)+(YY(2,1)*ALOG10(XB(J)))
      BD(J)=((STC(J)*6.0*DP)/(AG*(DD-DG)))**(1.0/3.0)
101  CONTINUE
      RETURN
      END
```



```

SUBROUTINE CORREL(XB,YF,F,L,T,N,DC,HT,T,Z,BRASS,KK)
C SUBROUTINE TO CALCULATE THE RATE FROM THE CORRELATION.
C RR - RATE FROM THE DATA.
C RR1 - RATE FROM THE CORRELATION,(EQUATION 37)
C D1, D2 - CONSTANTS.
DIMENSION XB(20), YF(20), F(20), Z(5,5), RR(20),
1RR1(20), DEV(20), PERDEV(20)
JKJ=KK+40
WT=378.476
STD=0.0
DO 100 J=1,N
RR(J)=((F(J)*YF(J))/(T*FLOAT(L)*WT))
D1=0.79E-6
D2=0.14E-2
XZ=D1-(D2*XB(J)/378.476 )
RR1(J)=(FLOAT(L)**1.4*XZ)/(DC**2.5)
DEV(J)=RR(J)-RR1(J)
PERDEV(J)=(DEV(J)*100.0)/RR(J)
STD=STD+PERDEV(J)**2
100 CONTINUE
WRITE(6,300)
WRITE(6,301)JKJ
WRITE(6,480)
IF(KK.NE.21)GO TO 104
WRITE(6,400)
WRITE(6,490)
GO TO 103
104 WRITE(6,401)
103 WRITE(6,302)DC, L
WRITE(6,510) BRASS, (Z(1,I), I=1,3)
WRITE(6,303)T, HT
WRITE(6,304)
WRITE(6,305)
WRITE(6,306)(RR(I), RR1(I), DEV(I), I=1,N)
300 FORMAT('1' )
301 FORMAT('0', 40X, 'C - ', I3)
480 FORMAT('-'/////////)
400 FORMAT('0', 37X, 'TABLE - (C-3).' )
490 FORMAT('- ',20X,'CALCULATED RATE OF SEPARATION FROM',
1' THE CORRELATION ' )
401 FORMAT('0', 34X, 'TABLE - (C-3).(CONTD)' )
302 FORMAT('0',14X,'DIA.OF COLUMN =',F6.2,'IN.',17X,
1'FEED RATE =', I5, 'CC/MIN.' )
510 FORMAT(15X, 'DIA.OF DIFFUSER =',F6.2,'IN.',15X,
1'DIFFUSER = ', 3A4 )
303 FORMAT(15X, 'RESIDENCE TIME =',F8.2,'MIN.',13X,
1'LIQUID LEVEL =',F7.2,'IN.')
304 FORMAT('0',25X,'RATE',20X,'RATE(CALC)',14X,'DEVIATION'
1) S
305 FORMAT(20X, '(G.MOLE/LIT-MIN)', 8X, '(G.MOLE/LIT-MIN)'
1) S
306 FORMAT(20X, E16.8, 8X, E16.8, 8X, E16.8 )

```



```
SIGMA=SQRT(STD)/FLOAT(L)
JKJ=JKJ+1
WRITE(6,600)SIGMA
600  FORMAT('0',25X,'PER CENT STANDARD DEVIATION OBTAINED ='
1, E16.8 )  S
RETURN
END
```



```

SUBROUTINE FOURTH(XB, G, BD, DC, F, N, KK, L, T, HT, Z,
1 BRASS) S

```

```

C
C SUBROUTINE TO CALCULATE F, F.D, F.DSQ, F.DSQ.DC**0.2,
C TDR, AND VF.
C
C
C IN THIS SUBROUTINE FOR WRITING PURPOSES ONLY F IS USED
C AS FOAM RATIO.
C PA - PHI/4.
C FF - FOAM RATIO =(F)-DIMENSIONLESS.
C VF - FOAM VELOCITY-(CM/SECOND).
C TDR - DRAINAGE TIME-(SECCNDS).
C BD - BUBBLE DIAMETER=(D)-(CM).
C FF2 - F.D-(CM).
C FF3 - F.DSQ.-(CMSQ).
C FF4 - F.DSQ.DC**0.2
C

```

```

C
C DIMENSION XB(20), G(20), F(20), BD(20), V(20), FF(20),
1 FF2(20), FF3(20), FF4(20), TDR(20), VF(20), Z(5,5)

```

```

C JK=51+KK
C DC=DC*2.54
C DO 101 I=1,N
C PA=22.0/28.0
C V(I)=F(I)+G(I)
C FF(I)=F(I)/V(I)
C VF(I)=V(I)/(PA*(DC**2.0))
C VF(I)=VF(I)/60.0
C TDR(I)=(53.5*2.54)/VF(I)
C FF2(I)=FF(I)*BD(I)
C FF3(I)=FF(I)*(BD(I)**2.0)
C FF4(I)=FF3(I)*(DC**0.2)

```

```

101 CONTINUE
C DC=DC/2.54
C WRITE(6,300)
C WRITE(6,301)JK
C WRITE(6,515)
C IF(KK.NE.21) GO TO 104
C WRITE(6,400)
C WRITE(6,490)
C GO TO 103

```

```

104 WRITE(6,401)
103 WRITE(6,302)DC, L
C WRITE(6,510) BRASS, (Z(1,I), I=1,3)
C WRITE(6,303)T, HT
C WRITE(6,304)
C WRITE(6,305)
C WRITE(6,306)(G(I), XB(I), BD(I), I=1,N)
C WRITE(6,307)
C WRITE(6,308)
C WRITE(6,309)(FF(J), TDR(J), FF2(J), J=1,N)
C WRITE(6,310)

```



```

      WRITE(6,311)
      WRITE(6,312)(FF3(K), FF4(K), VF(K), K=1,N)
300  FORMAT('1' )
301  FORMAT('0', 40X, 'C - ', I3)
515  FORMAT('-'//)
400  FORMAT('0', 37X, 'TABLE - (C-4). ' )
490  FORMAT('-',15X,'FCAM RATIO, FOAM VELOCITY, DRAINAGE',
1' TIME, F.DSQ, F.DSQ.DC**0.2 ' )
401  FORMAT('0', 34X, 'TABLE - (C-4).(CONTD)' )
302  FORMAT('0',14X,'DIA.OF COLUMN =',F6.2,'IN.',17X,
1'FEED RATE =', I5, 'CC/MIN.' )
510  FORMAT(15X, 'DIA.OF DIFFUSER =',F6.2,'IN.',15X,
1'DIFFUSER = ', 3A4 )
303  FORMAT(15X, 'RESIDENCE TIME =',F8.2,'MIN.',13X,
1'LIQUID LEVEL =',F7.2,'IN.')
304  FORMAT('-',26X,'GAS RATE',10X,'XB',10X,'BUBBLE DIA',
1'METER' )
305  FORMAT(27X, '(CC/MIN)',8X,'(G/L)',14X,'(CM)' )
306  FORMAT(26X,F7.1,6X,F10.5,8X,F11.6 )
307  FORMAT('-',27X,'F', 16X,'TDR',16X,'F.D' )
308  FORMAT(45X,'(SEC)',14X,'(CM)' )
309  FORMAT(20X,E16.8, 3X, E16.8,3X,E16.8 )
310  FORMAT('-', 25X,'F.DSQ',11X,'F.DSQ.DC**0.2', 10X, 'VF'
1)          S
311  FORMAT(26X,'(CMSQ)',30X,'(CM/SEC)' )
312  FORMAT(20X, E16.8, 3X,E16.8, 3X, E16.8 )
      RETURN
      END

```


TABLE LISTING

NO.	TITLE	PAGE NO.
C - 1	EFFECT OF (G'/L) ON STRIPPING RATIO	C - 21
C - 2	RATE OF SEPARATION AND DECONTAMINATION FACTOR	C - 32
C - 3	CALCULATED RATE OF SEPARATION FROM THE CORRELATION	C - 61
C - 4	FOAM RATIO, FOAM VELOCITY, DRAINAGE TIME, F.DSQ, F.DSQ.DC**0.2	C - 72

TABLE - (C-1).
EFFECT OF (G./GATE/L) ON STRIPPING RATIO

DIA. OF COLUMN = 2.00 IN.
DIA. OF DIFFUSER = 1.25 IN.
RESIDENCE TIME = 28.94 MIN.

FEED RATE = 25 CC/MIN.
DIFFUSER = BRASS - D1
LIQUID LEVEL = 14.00 IN.

G./GATE/L	X _B /X _L
6.000	0.7333
8.000	0.6400
10.000	0.4933
12.000	0.4667
14.000	0.4200
16.000	0.3667

TABLE - (C-1). (CONTD)

DIA. OF COLUMN = 3.00 IN.

FEED RATE = 5000 CC/MIN.

DIA. OF DIFFUSER = 1.25 IN.

DIFFUSER = BRASS - D1

RESIDENCE TIME = 14.42 MIN.

LIQUID LEVEL = 14.00 IN.

G. RATE/L

XB/XL

2.000

0.7667

4.000

0.6933

5.000

0.6200

6.000

0.4933

6.500

0.4600

7.000

0.4267

8.000

0.3667

10.000

0.5120

TABLE - (C-1). (CONT'D)

DIA. OF COLUMN = 2.0 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 9.61 MIN.

FEED RATE = 75 CC/MIN.
 DIFFUSER = BRASS - 01
 LIQUID LEVEL = 14.00 IN.

G. RATE/L

XB/XL

2.000

0.7033

2.467

0.8200

3.333

0.7533

4.000

0.7133

4.467

0.7267

5.333

0.6867

6.000

0.6867

6.667

0.6733

TABLE - (C-1). (CONTD)

DIA. OF COLUMN = 2.5 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 45.76 MIN.

FEED RATE = 25 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.00 IN.

G. RATE/L	X _B /X _L
6.000	0.5760
8.000	0.5440
10.000	0.4653
12.000	0.3733
14.000	0.3307
16.000	0.2887
18.000	0.2560
20.000	0.2347

TABLE - (C-1). (CONT'D)

DIA. OF COLUMN = 2.5 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 22.53 MIN.

FEED RATE = 50 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.00 IN.

Q, RATE/L	X _B /X _L
3.000	0.7200
4.000	0.6667
5.000	0.6267
6.000	0.6433
7.000	0.6067
8.000	0.5867
9.000	0.5833
10.000	0.5333

TABLE - (C-1). (CONT'D)

DIA. OF COLUMN = 2.0 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 15.02 MIN.

FEED RATE = 75 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.07 IN.

G. RATE/L	XB/XL
2.000	0.8000
2.667	0.7627
3.333	0.7467
4.000	0.7147
4.667	0.6933
5.333	0.6597
6.000	0.6267
6.667	0.5813

TABLE - (C-1). (CONT'D)

DIA. OF COLUMN = 4.75 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 115.36 MIN.

FEED RATE = 2500 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.00 IN.

G. RATE/L	X _B /X _L
24.000	0.3000
32.000	0.3000
40.000	0.2507
48.000	0.2133
64.000	0.2133
80.000	0.2133

TABLE - (C-1). (CONTD)

DIA. OF COLUMN = 4.0 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 07.49 MIN.

FEED RATE = 50 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.00 IN.

Q, RATE/L	X _B /X _L
12.000	0.5000
16.000	0.4933
20.000	0.4267
24.000	0.3333
32.000	0.3470
40.000	0.3000
60.000	0.2567

TABLE - (C-1). (CONTD)

DIA. OF COLUMN = 4.0 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 48.45 MIN.

FEED RATE = 75 CC/MIN.
 DIFFUSER = BRASS - DI
 LIQUID LEVEL = 14.00 IN.

G. RATE/L	X _B /X _L
8.000	0.6400
10.667	0.5667
13.333	0.5533
16.000	0.5133
21.333	0.5000
26.667	0.4467
33.333	0.4267
40.000	0.4267

TABLE - (C-1). (CONT'D)

DIA. OF COLUMN = 8.00 IN.

DIA. OF DIFFUSER = 1.25 IN.

RESIDENCE TIME = 129.78 MIN.

FEED RATE = 5000 CC/MIN.

DIFFUSER = BRASS - D1

LIQUID LEVEL = 14.00 IN.

G. RATE/L

30.000

36.000

42.000

50.000

57.000

80.000

XB/XL

0.4267

0.4213

0.4053

0.3520

1.2827

0.2613

TABLE - (C-1). (CONTO)

DIA. OF COLUMN = 1.0 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 66.52 MIN.

FEED RATE = 7500/MIN.
 DIFFUSER = GRASS - D1
 LIQUID LEVEL = 14.00 IN.

Q. RATE/L	X _B /X _L
24.000	0.5333
26.667	0.5173
33.333	0.5013
36.000	0.4693
40.000	0.4373
46.667	0.4213
53.333	0.3947

TABLE - (C-2).

RATE OF SEPARATION AND DECONTAMINATION FACTOR

DIA.OF COLUMN = 2.00IN.
 DIA.OF DIFFUSER = 1.25IN.
 RESIDENCE TIME = 28.84MIN.

FEED RATE = 25CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.00IN.

XB (GMOLE/L)	RATE (G.MOLE/LIT-MIN)	RATE(CALULATED) (G.MOLE/LIT-MIN)	DIFFERENCE
0.29064E-03	0.49277860E-05	0.42091415E-05	0.71864451E-06
0.25365E-03	0.56434865E-05	0.62797299E-05	-0.63624339E-06
0.19552E-03	0.86337977E-05	0.95335145E-05	-0.89971672E-06
0.18495E-03	0.10060792E-04	0.10125105E-04	-0.64313099E-07
0.16646E-03	0.11737524E-04	0.11160406E-04	0.57711804E-06
0.14532E-03	0.12648149E-04	0.12343597E-04	0.30455249E-06

CONSTANTS ARE : INTERCEPT = 0.20478066E-04 SLOPE = -0.55976376E-01

THE STANDARD DEVIATION OBTAINED = 0.24498843E-06

GAS RATE (CC/MIN)	(D.F-1)	(D.F-1) (CALCULATED)	DIFFERENCE
150.0	0.3636	0.3789	-0.0152
200.0	0.5625	0.5980	-0.0355
250.0	1.0270	0.8519	0.1751
300.0	1.1429	1.1376	0.0052
350.0	1.3810	1.4527	-0.0718
400.0	1.7273	1.7955	-0.0682

CONSTANTS ARE: INTERCEPT = 0.13388089E-03 SLOPE = 0.15862265E 01

THE STANDARD DEVIATION OBTAINED= 0.34150489E-01

TABLE - (C-2). (CONT'D)

DIA. OF COLUMN = 1.0 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 14.42 MIN.

FEED RATE = 50 CC/MIN.
 DIFFUSER = GRASS - D1
 LIQUID LEVEL = 14.00 IN.

X ₂ (G.MOLE/L)	RATE (G.MOLE/LIT-MIN)	RATE (CALCULATED) (G.MOLE/LIT-MIN)	DIFFERENCE
0.37335E-03	0.6315158E-05	0.70704049E-05	-0.26324567E-06
0.27479E-03	0.02915133E-05	0.99812314E-05	-0.59069316E-06
0.24572E-03	0.12438059E-04	0.12863172E-04	-0.39411316E-06
0.19532E-03	0.16570447E-04	0.17395334E-04	-0.13248937E-05
0.18231E-03	0.17807210E-04	0.19214349E-04	-0.13164390E-05
0.16910E-03	0.18004300E-04	0.20537364E-04	-0.24485635E-05
0.14532E-03	0.23405362E-04	0.22907567E-04	0.58779551E-06
0.20232E-03	0.22906397E-04	0.17156664E-04	0.57502330E-05

CONSTANTS ARE: INTERCEPT = 0.37416753E-04 SLOPE = -0.99843214E-01

THE STANDARD DEVIATION OBTAINED = 7.82412862E-06

GAS RATE (CC/MIN)	(D.F-1)	(D.F-1) (CALCULATED)	DIFFERENCE
150.0	0.3043	0.3432	-0.0388
200.0	0.4423	0.5036	-0.0607
250.0	0.6129	0.6766	-0.0639
300.0	0.8271	0.8625	-0.1646
325.0	1.1739	0.9593	0.2146
350.0	1.2438	1.0586	0.2851
400.0	1.7273	1.2643	0.4630
500.0	0.9531	1.7710	-0.7479

CONSTANTS ARE: INTERCEPT = 0.43570695E-03 SLOPE = 0.13295927E-01

THE STANDARD DEVIATION OBTAINED = 0.12102187E-05

TABLE - (C-2). (CONT'D)

DIA. OF COLUMN = 2.0 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 0.51 MIN.

FEED RATE = 75 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.00 IN.

x_2 (G.MOLE/L)	RATE (G.MOLE/LIT-MIN)	RATE (CALCULATED) (G.MOLE/LIT-MIN)	DIFFERENCE
0.31442E-02	0.00017578E-05	0.17061412E-04	-0.12596547E-05
0.32400E-02	0.000096934E-05	0.72044850E-05	0.15034075E-05
0.29357E-02	0.14060354E-04	0.14211386E-04	-0.15203204E-06
0.28271E-02	0.18061211E-04	0.18361359E-04	-0.23001485E-05
0.28804E-02	0.17741731E-04	0.16978540E-04	0.76329161E-06
0.27218E-02	0.00022415E-04	0.21128113E-04	-0.90386311E-06
0.27214E-02	0.21602045E-04	0.21128015E-04	0.47423237E-06
0.26685E-02	0.0002386234E-04	0.22511455E-04	0.13748533E-05

CONSTANTS ARE: INTERCEPT = 0.92359650E-04 SLOPE = -0.26177913E-00

THE STANDARD DEVIATION OBTAINED = 0.47260873E-05

GAS RATE (CC/MIN)	(D.F-1)	(D.F-1) (CALCULATED)	DIFFERENCE
150.0	0.2605	0.2311	0.0294
200.0	0.2125	0.2773	-0.0648
250.0	0.2274	0.3193	-0.0919
300.0	0.4613	0.3584	0.1029
350.0	0.3761	0.3951	-0.0190
400.0	0.4553	0.4350	0.0203
450.0	0.4563	0.4633	-0.0070
500.0	0.4851	0.4952	-0.0101

CONSTANTS ARE: INTERCEPT = 0.96450844E-02 SLOPE = 0.63290651E-02

THE STANDARD DEVIATION OBTAINED = 0.10722542E-01

TABLE - (C-2). (CONTD)

DIA. OF COLUMN = 2.5 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 25.55 MIN.

FEED RATE = 25CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.5 IN.

X_2 (GM/L)	X_1 (G. MOLE / LIT-MIN)	X_1 (CALCULATED) (G. MOLE / LIT-MIN)	DIFFERENCE
0.2282E-03	1.41038449E-05	1.42621013E-05	0.18435458E-08
0.2155E-03	1.40735483E-05	1.40489067E-05	0.22674158E-06
0.16164E-02	1.50910793E-05	1.53254874E-05	-0.33360811E-06
0.14794E-03	1.58663355E-05	1.67123910E-05	-0.47005415E-07
0.13115E-03	1.71371278E-05	1.72233637E-05	-0.91155925E-07
0.11414E-03	1.77599552E-05	1.77441355E-05	0.15819751E-07
0.10146E-03	1.81513523E-05	1.81311391E-05	0.27843271E-07
0.93055E-04	1.85916404E-05	1.83839754E-05	0.19956497E-06

CONSTANTS ARE: INTERCEPT = 0.11226271E-04 SLOPE = -0.30507050E-01

THE STANDARD DEVIATION OBTAINED = 0.57835955E-07

GAS RATE (CC/MIN)	$(X_1 - 1)$	$(X_1 - 1)$ (CALCULATED)	DIFFERENCE
100.0	0.7351	0.6822	0.0539
200.0	0.8382	0.4930	-0.1548
300.0	1.4671	1.3287	0.1384
350.0	1.6786	1.6856	-0.0070
380.0	2.0240	2.0612	-0.0370
400.0	2.4722	2.4536	0.0187
450.0	2.9052	2.3612	0.5450
500.0	3.2614	3.2829	-0.0216

CONSTANTS ARE: INTERCEPT = 0.93659715E-03 SLOPE = 0.13049717E-01

THE STANDARD DEVIATION OBTAINED = 0.23629732E-01

TABLE - (C-2). (CONTD)

DIA. OF COLUMN = 2.50 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 22.53 MIN.

FEED RATE = 500 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.00 IN.

X ₁ (G.MOLE/L)	DATE (G.MOLE/LIT-MIN)	RATE (CALCULATED) (G.MOLE/LIT-MIN)	DIFFERENCE
0.23535E-03	0.52059499E-05	0.51575555E-05	1.48994480E-07
0.26423E-03	0.60558413E-05	0.68620575E-05	0.61783794E-07
0.24044E-03	0.35063692E-05	0.67791414E-05	-0.69077214E-06
0.25497E-03	0.78843761E-05	0.76575812E-05	-0.25679492E-06
0.24044E-03	0.35063692E-05	0.67791414E-05	-0.15389287E-06
0.23251E-03	0.03781477E-05	0.04131526E-05	-0.40015948E-07
0.23112E-03	0.98935799E-05	0.95246651E-05	0.36901383E-06
0.21137E-03	0.1127477E-04	0.11122247E-04	0.14822308E-06

CONSTANTS ARE : INTERCEPT = 0.29163107E-14 SLOPE = -0.80619454E-01

THE STANDARD DEVIATION OBTAINED = 0.16700120E-06

GAS RATE (CC/MIN)	(O.F-1)	(O.F-1) (CALCULATED)	DIFFERENCE
150.0	0.3889	0.3987	-0.0099
200.0	0.4550	0.4392	0.0158
250.0	0.6484	0.5733	0.0751
275.0	0.5544	0.6134	-0.0590
300.0	0.6484	0.6526	-0.0042
350.0	0.7565	0.7281	-0.0286
375.0	0.7143	0.7647	-0.0504
400.0	0.2757	0.8006	-0.0744

CONSTANTS ARE: INTERCEPT = 0.1132955E-01 SLOPE = 0.71066898E-00

THE STANDARD DEVIATION OBTAINED = 0.16765155E-01

TABLE - (C-2). (CONT'D)

DIA. OF COLUMN = 2.00 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 15.72 MIN.

FEED RATE = 75 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.00 IN.

X _R (GMOLE/L)	RATE (G. MOLE/LIT-MIN)	RATE (CALCULATED) (G. MOLE/LIT-MIN)	DIFFERENCE
0.3175E-03	0.5446052E-05	0.52651430E-05	0.38365215E-06
0.33226E-03	0.7210464E-05	0.74414129E-05	-0.42006657E-06
0.29592E-03	0.22751440E-05	0.33741324E-05	-0.98983494E-07
0.23324E-03	0.11103742E-04	0.10232615E-04	-0.12987311E-06
0.27479E-03	0.11103351E-04	0.11483236E-04	0.12309465E-06
0.25733E-03	0.12577143E-04	0.13971537E-04	0.66056600E-06
0.24930E-03	0.15527193E-04	0.15369646E-04	0.25745248E-06
0.23340E-03	0.1739423E-04	0.19112361E-04	-0.12153760E-06

CONSTANTS ARE : INTERCEPT = 0.51001590E-04 SLOPE = -0.14779155E-02

THE STANDARD DEVIATION OBTAINED = 0.83531347E-07

GAS RATE (CC/MIN)	(D.F-1)	(D.F-1) (CALCULATED)	DIFFERENCE
150.0	0.2507	0.2359	0.0141
200.0	0.3112	0.3003	0.0109
250.0	0.3323	0.3622	-0.0229
300.0	0.3893	0.4228	-0.0228
350.0	0.4423	0.4803	-0.0380
400.0	0.5359	0.5373	-0.0014
450.0	0.5957	0.5931	0.0027
500.0	0.7202	0.6474	0.0723

CONSTANTS ARE : INTERCEPT = 0.35211630E-02 SLOPE = 0.33914346E-07

THE STANDARD DEVIATION OBTAINED = 0.11204965E-01

TABLE - (C-2). (CONTD)

DIV. OF COLUMN = 4.00 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 115.86 MIN.

FEED RATE = 2500/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.00 IN.

KA (G.MOLE/L)	RATE (G.MOLE/LIT-MIN)	RATE (CALCULATED) (G.MOLE/LIT-MIN)	DIFFERENCE
0.11300E-03	0.24447454E-05	0.24535712E-05	-0.88248271E-08
0.11300E-03	0.24500463E-05	0.24535712E-05	0.54660632E-08
0.11510E-03	0.26023226E-05	0.26071693E-05	0.52623363E-08
0.24550E-04	0.27076653E-05	0.28261422E-05	-0.35976882E-07
0.44550E-04	0.28324013E-05	0.28266422E-05	0.58180376E-08
0.44550E-04	0.28549239E-05	0.28266422E-05	0.28281647E-07

CONSTANTS ARE: INTERCEPT = 0.37440754E-05 SLOPE = -0.10861461E-01

THE STANDARD DEVIATION OBTAINED = 0.79293478E-08

QMS RATE (CC/MIN)	(D.F-1)	(D.F-1) (CALCULATED)	DIFFERENCE
600.0	2.3533	2.2647	0.0887
800.0	2.3333	2.5932	-0.2599
1000.0	1.7517	2.8746	-0.1246
1200.0	3.6875	3.1300	0.5574
1600.0	3.6875	3.5000	0.1075
2000.0	3.6075	3.9731	-0.2856

CONSTANTS ARE: INTERCEPT = 0.11426431E-07 SLOPE = 0.46089051E-06

THE STANDARD DEVIATION OBTAINED = 0.11668709E-06

TABLE - (C-2). (CONT'D)

DIA. OF COLUMN = 4.3 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 47.46 MIN.

FEED RATE = 5000 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.0 IN.

X = (G.MOLE/L)	RATE (G.MOLE/LIT-MIN)	RATE (CALCULATED) (G.MOLE/LIT-MIN)	DIFFERENCE
0.19316E-03	0.3570194E-05	0.31898871E-05	0.31713762E-06
0.19532E-03	0.36270525E-05	0.32351945E-05	0.39285876E-06
0.16917E-03	0.25645836E-05	0.26871479E-05	-0.73256433E-06
0.12211E-03	0.42077621E-05	0.43207198E-05	-0.56257704E-07
0.13479E-03	0.37525516E-05	0.42748143E-05	-0.52226369E-06
0.11800E-03	0.44322423E-05	0.45460465E-05	-0.11380416E-06
0.17569E-03	0.54970752E-05	0.47720732E-05	0.71493196E-06

CONSTANTS ARE : INTERCEPT = 0.65972400E-05 SLOPE = -0.17109126E-01

THE STANDARD DEVIATION OBTAINED = 0.18022439E-05

GAS RATE (CC/MIN)	(O.F-1)	(O.F-1) (CALCULATED)	DIFFERENCE
800.0	1.0000	0.9842	0.0158
1000.0	1.0273	1.2104	-0.1734
1200.0	1.3438	1.4073	-0.0566
1400.0	2.0000	1.5881	0.4119
1600.0	1.9412	1.9371	0.0041
1800.0	2.3323	2.2597	0.0736
2000.0	2.7500	2.9896	-0.2396

CONSTANTS ARE : INTERCEPT = 0.11847893E-01 SLOPE = 0.69037366E-02

THE STANDARD DEVIATION OBTAINED = 0.73677421E-01

TABLE - (C-2). (CONTD)

DIA. OF COLUMN = 4.00 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 33.45 MIN.

FEED RATE = 75 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.00 IN.

KE (G.MOLE/L)	RATE (G.MOLE/LIT-MIN)	RATE (CALCULATED) (G.MOLE/LIT-MIN)	DIFFERENCE
0.25205E-03	0.37031914E-05	0.35954917E-05	0.107699963E-06
0.27458E-03	0.67376789E-05	0.48091570E-05	-0.77513252E-07
0.21035E-03	0.50065501E-05	0.50134640E-05	-0.69139787E-08
0.20440E-03	0.59220411E-05	0.55253743E-05	-0.10343319E-06
0.12110E-03	0.50174345E-05	0.58306753E-05	-0.32705429E-08
0.17703E-03	0.60457209E-05	0.66478924E-05	-0.10216354E-06
0.16310E-03	0.70177255E-05	0.69543573E-05	0.83375198E-07
0.16310E-03	0.70177255E-05	0.69543573E-05	0.10226631E-06

CONSTANTS ARE: INTERCEPT = 0.13492357E-04 SLOPE = -0.3866235E-01

THE STANDARD DEVIATION OBTAINED = 0.29636432E-07

GAS RATE (CC/MIN)	(O.F-1) (O.F-1)	(O.F-1) (CALCULATED)	DIFFERENCE
600.0	0.5675	0.6154	-0.0529
800.0	0.7647	0.7174	0.0473
1000.0	0.9072	0.8087	-0.0985
1200.0	1.0461	0.8904	0.1557
1400.0	1.0730	1.0380	-0.0381
2000.0	1.2088	1.1490	0.0698
2500.0	1.3438	1.3166	0.0271
3000.0	1.3438	1.4517	-0.1072

CONSTANTS ARE: INTERCEPT = 0.23359240E-01 SLOPE = 0.53188263E-01

THE STANDARD DEVIATION OBTAINED = 0.21522507E-01

TABLE - (C-2). (CONTD)

DIA. OF COLUMN = 0.4 IN.
DIA. OF DIFFUSER = 1.25 IN.
RESIDUAL TIME = 123.76 MIN.

FEED RATE = 500 CC/MIN.
DIFFUSER = BRASS - U1
LIQUID LEVEL = 14.00 IN.

X _R (GMOLE/L)	Y _R (G. MOLE/LIT-MIN)	RATE (CALCULATED) (G. MOLE/LIT-MIN)	DIFFERENCE
0.15910E-03	0.17435321E-05	0.13123813E-05	-0.39249244E-07
0.16889E-03	0.18113836E-05	0.13149358E-05	-0.13052158E-07
0.16884E-03	0.18117336E-05	0.13511046E-05	0.38628968E-07
0.17451E-03	0.2009186E-05	0.19716654E-05	0.95253199E-07
0.1823E-03	0.18647934E-05	0.21283459E-05	-0.26367249E-06
0.18957E-03	0.2000517E-05	0.21765219E-05	-0.18203082E-06

CONSTANTS: INTERCEPT = 0.27573732E-05 SLOPE = -0.57037100E-02

THE STANDARD DEVIATION OBTAINED = 0.56494248E-07

GAS RATE (CC/MIN)	(O.F-1)	(O.F-1) (CALCULATED)	DIFFERENCE
1500.0	1.3478	1.2746	0.1092
1800.0	1.3734	1.4471	-0.0736
2000.0	1.4671	1.5861	-0.1190
2200.0	1.4400	1.9264	-0.4855
2400.0	1.5377	2.2573	-0.2798
2600.0	1.8265	2.9059	-0.1743

CONSTANTS: INTERCEPT = 0.2114750E-02 SLOPE = 0.87090477E-03

THE STANDARD DEVIATION OBTAINED = 0.58365561E-01

TABLE - (C-2). (CONTD)

DIA. OF COLUMN = 0.5 IN.
 DIA. OF PIPET = 0.25 IN.
 RESIDENCE TIME = 26.6 MIN.

FEED RATE = 7500/MIN.
 DIFFUSER = BRASS - 01
 LIQUID LEVEL = 14.0 IN.

X ₂ (G.MOLE/L)	X ₁ (G.MOLE/LIT-MIN)	RATE(CALCULATED) (G.MOLE/LIT-MIN)	DIFFERENCE
0.21337E-03	0.2141112E-05	0.21449323E-05	0.31177478E-08
0.22372E-03	0.2144741E-05	0.22246563E-05	-0.3313136E-07
0.19960E-03	0.2142298E-05	0.23143293E-05	0.28669792E-07
0.18611E-03	0.21476125E-05	0.24833745E-05	0.13938006E-07
0.17233E-03	0.21413581E-05	0.25532215E-05	-0.96633812E-08
0.14602E-03	0.27363683E-05	0.27371946E-05	-0.23337534E-08
0.15543E-03	0.24712915E-05	0.28788163E-05	-0.52477844E-09

CONSTANTS AND INTERCEPT = 0.41574236E-05 SLOPE = -0.13352830E-01

THE STANDARD DEVIATION OBTAINED = 0.67399668E-08

GAS RATE (CC/MIN)	(O.F-1)	(O.F-1) (CALCULATED)	DIFFERENCE
1000.0	0.8750	0.8527	0.0223
2000.0	0.9330	0.9199	0.0131
3000.0	0.9947	1.0804	-0.0857
3700.0	1.1507	1.1420	0.0087
3800.0	1.2565	1.2321	0.0245
3900.0	1.3734	1.3768	-0.0034
4000.0	1.5038	1.5159	-0.0121

CONSTANTS AND INTERCEPT = 0.33455732E-02 SLOPE = 0.72158433E-00

THE STANDARD DEVIATION OBTAINED = 0.15284672E-01

TABLE - (C-2). (CONTD)

PISTON VOLUME = 2.0 IN.
 DIA. OF DIFFUSER = 0.25 IN.
 RESIDENCE TIME = 115.56 MIN.

FEED RATE = 2500 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 50.00 IN.

X- (G.MOLE/L)	Y- (G.MOLE/LIT-MIN)	RATE (CALCULATED) (G.MOLE/LIT-MIN)	DIFFERENCE
0.24510E-12	0.19113661E-05	0.13523315E-05	0.63534071E-17
0.20716E-12	0.1834453E-05	0.19484723E-05	-0.11901739E-06
0.19235E-12	0.2169978E-05	0.21801106E-05	-0.10132680E-07
0.17544E-12	0.2402603E-05	0.2444840E-05	-0.47820322E-07
0.14726E-12	0.29022307E-05	0.2975264E-05	-0.17804266E-07

CONSTANTS ARE: INTERCEPT = 0.51914149E-05 SLOPE = -0.15655309E-01

THE STANDARD DEVIATION OBTAINED = 0.28919338E-07

GAS RATE (CC/MIN)	(O.F-1)	(O.F-1) (CALCULATED)	DIFFERENCE
150.0	1.6104	1.6428	-0.0324
200.0	1.9133	1.8547	0.0586
250.0	1.7608	1.7646	-0.0038
300.0	1.2570	1.2747	-0.0177
450.0	1.6728	1.6935	-0.0207

CONSTANTS ARE: INTERCEPT = 0.45557267E-02 SLOPE = 0.98773532E-01

THE STANDARD DEVIATION OBTAINED = 0.13702534E-01

TABLE - (C-2). (CONT'D)

DIA. OF COLUMN = 2.0 IN.
DIA. OF DIFFUSER = 1.25 IN.
RESIDENCE TIME = 87.68 MIN.

FEED RATE = 500 CC/MIN.
DIFFUSER = BRASS - D1
LIQUID LEVEL = 56.00 IN.

X_F (G.MOLE/L)	K_F (G. MOLE/LIT-MIN)	RATE (CALCULATED) (G. MOLE/LIT-MIN)	DIFFERENCE
0.23035E-05	0.31024065E-05	0.23069223E-05	0.34148434E-06
0.23045E-05	0.31216138E-05	0.35486591E-05	-0.22704535E-06
0.22617E-05	0.31194099E-05	0.36442793E-05	-0.22496988E-06
0.22405E-05	0.31173152E-05	0.36922893E-05	-0.84974090E-07
0.21415E-05	0.37477732E-05	0.37881664E-05	-0.10331860E-08
0.21454E-05	0.37316311E-05	0.39073814E-05	0.23738721E-07
0.20715E-05	0.42404162E-05	0.41755640E-05	0.17285220E-06

CONSTANTS ARE: INTERCEPT = 0.97706794E-05 SLOPE = -0.22665676E-01

THE STANDARD DEVIATION OBTAINED = 7.72342051E-07

GAS RATE (CC/MIN)	(D.F.-1)	(D.F.-1) (CALCULATED)	DIFFERENCE
250.0	.6593	0.6634	-0.0041
300.0	.7202	0.7073	0.0129
350.0	.7523	0.7406	0.0117
400.0	.7639	0.7624	-0.0015
450.0	.9020	0.8155	-0.0865
500.0	.8473	0.8462	0.0011
600.0	.9133	0.9122	0.0011

CONSTANTS ARE: INTERCEPT = 0.95451355E-01 SLOPE = 0.35113293E-00

THE STANDARD DEVIATION OBTAINED = 0.37364587E-02

TABLE - (C-2). (CONTD)

DIA. OF COLUMN = . . . IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 25.45 MIN.

FEED RATE = 75 CC/MIN.
 DIFFUSER = BRASS - 01
 LIQUID LEVEL = 56.00 IN.

X	Y	RATE	RATE (CALCULATED)	DIFFERENCE
(G/MOLE/L)		(G. MOLE/LIT-MIN)	(G. MOLE/LIT-MIN)	
0.31203E-05		0.24077753E-05	0.24329638E-05	0.64821506E-07
0.29324E-05		0.40016421E-05	0.39820855E-05	0.18766514E-07
0.27586E-05		0.40027504E-05	0.46471387E-05	-0.10838630E-06
0.25782E-05		0.51842417E-05	0.53113791E-05	-0.12703731E-06
0.24711E-05		0.50491741E-05	0.58642166E-05	-0.15782462E-07
0.24007E-05		0.61647294E-05	0.61970351E-05	0.16762445E-06

CONSTANTS ARE: INTERCEPT = 0.18317766E-4 SLOPE = -0.52375462E-01

THE STANDARD DEVIATION OBTAINED = 0.41099657E-07

GAS RATE	(O.F-1)	(O.F-1)	DIFFERENCE
(CC/MIN)		(CALCULATED)	
250.0	0.2659	0.2633	-0.0014
300.0	0.3093	0.3094	-0.0001
350.0	0.4648	0.4646	0.0003
400.0	0.5552	0.5296	0.0073
450.0	0.6026	0.5945	0.0081
500.0	0.6447	0.5592	-0.0145

CONSTANTS ARE: INTERCEPT = 0.14015825E-12 SLOPE = 0.98122436E-00

THE STANDARD DEVIATION OBTAINED = 0.39301530E-02

TABLE - (C-2).(CONTD)

DIA. OF COLUMN = 2.5 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 18.64 MIN.

FEED RATE = 2500/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 8.96 IN.

X ₂ (MOLE/L)	RATE (G. MOLE/LIT-MIN)	RATE(CALCULATED) (G. MOLE/LIT-MIN)	DIFFERENCE
0.22351E-02	0.67772404E-05	0.62877652E-05	0.91475153E-07
0.17755E-02	0.60230561E-05	0.90135641E-05	-0.54757948E-07
0.14736E-02	0.1441291E-04	0.17439137E-04	0.21527740E-08
0.12642E-02	0.11158767E-04	0.11539480E-04	-0.37071914E-06
0.11414E-02	0.12173317E-04	0.12169685E-04	0.86256478E-08
0.10569E-02	0.12313124E-04	0.12589822E-04	0.22330172E-06

CONSTANTS ARE: INTERCEPT = 0.17341536E-04 SLOPE = -0.49691174E-01

THE STANDARD DEVIATION OBTAINED = 0.53698328E-07

GAS RATE (CC/MIN)	(D.F-1)	(D.F-1) (CALCULATED)	DIFFERENCE
160.0	0.7745	0.7748	-0.0002
200.0	1.2321	1.1521	0.0801
270.0	1.6786	1.5672	0.1114
300.0	2.1250	2.0151	0.1099
360.0	2.4722	2.4024	-0.0692
400.0	2.7500	2.9964	-0.2464

CONSTANTS ARE: INTERCEPT = 0.77331765E-01 SLOPE = 0.13789988E-01

THE STANDARD DEVIATION OBTAINED = 0.51890690E-01

TABLE - (C-2). (CONT'D)

DIA. OF COLUMN = 2.40 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 14.42 MIN.

FEED RATE = 500 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 8.96 IN.

C ₂ (G.MOLE/L)	RATE (G. MOLE/LIT-MIN)	RATE (CALCULATED) (G. MOLE/LIT-MIN)	DIFFERENCE
0.24170E-03	0.16916920E-04	0.64171772E-04	0.6451507E-07
0.27479E-03	0.15867092E-04	0.10321246E-04	0.49580558E-06
0.22928E-03	0.15557031E-04	0.15814955E-04	-0.26292400E-06
0.21137E-03	0.17034268E-04	0.17794038E-04	-0.75977005E-06
0.19446E-03	0.19633905E-04	0.19768122E-04	-0.73421688E-06
0.18812E-03	0.20110349E-04	0.2050347E-04	-0.39755832E-06
0.19178E-03	0.20032525E-04	0.21248692E-04	0.86383325E-06
0.17313E-03	0.20026179E-04	0.22235734E-04	0.79144548E-06

CONSTANTS ARE: INTERCEPT = 0.42470156E-04 SLOPE = -0.11674100E-00

THE STANDARD DEVIATION OBTAINED = 0.21155324E-06

GAS RATE (CC/MIN)	(D.F-1)	(D.F-1) (CALCULATED)	DIFFERENCE
150.0	0.3587	0.3697	-0.0103
200.0	0.4429	0.5081	-0.0658
250.0	0.7361	0.6512	0.0850
300.0	0.8750	0.7975	0.0775
350.0	1.0380	0.9466	0.0915
400.0	1.1907	1.0981	0.1086
450.0	1.2902	1.2517	-0.0715
500.0	1.2864	1.4073	-0.1207

CONSTANTS ARE: INTERCEPT = 0.14043525E-02 SLOPE = 0.11118755E-01

THE STANDARD DEVIATION OBTAINED = 0.26747651E-01

TABLE - (C-2). (CONTO)

DIA. OF COLUMN = 2.5 IN.
 DIA. OF DIFFUSOR = 1.25 IN.
 RESIDENCE TIME = 9.41 MIN.

FEED RATE = 7500/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 3.96 IN.

XIN (G.MOLE/L)	RATE (G.MOLE/LIT-MIN)	RATE(CALCULATED) (G.MOLE/LIT-MIN)	DIFFERENCE
0.314425-03	0.124216222E-04	0.81507460E-05	0.13408762E-05
0.293289-03	0.12471082E-04	0.12422273E-04	-0.15039132E-06
0.27254E-03	0.15815562E-04	0.17429222E-04	-0.16135600E-05
0.277437-03	0.16443199E-04	0.15975907E-04	0.64293361E-07
0.254657-03	0.19041702E-04	0.21006432E-04	-0.20047300E-05
0.243785-03	0.22293710E-04	0.23242183E-04	-0.55848795E-06
0.23574E-03	0.26133504E-04	0.24583642E-04	0.14301622E-05
0.23251E-03	0.25371200E-04	0.25477930E-04	0.14922698E-05

CONSTANTS: INTERCEPT = 0.74564948E-04 SLOPE = -0.21154660E-00

THE STANDARD DEVIATION OBTAINED = 0.45123704E-06

GAS RATE (CC/MIN)	(D.F-1)	(D.F-1) (CALCULATED)	DIFFERENCE
1500	0.2605	0.2727	-0.0122
2000	0.3614	0.3452	0.0161
2500	0.4645	0.4145	0.0503
3000	0.4236	0.4814	-0.0528
3500	0.5625	0.5462	0.0163
4000	0.6304	0.6094	0.0210
4500	0.6741	0.6712	0.0029
5000	0.7545	0.7318	0.0223

CONSTANTS: INTERCEPT = 0.44787452E-02 SLOPE = 0.82043260E-00

THE STANDARD DEVIATION OBTAINED = 0.11430381E-01

TABLE - (C-2). (CONTD)

DIA. OF COLUMN = 2.50 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 116.36 MIN.

FEED RATE = 250.0/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 35.00 IN.

K ₁ (G/MOLE/L)	RATE (G. MOLES/LIT-MIN)	RATE (CALCULATED) (G. MOLE/LIT-MIN)	DIFFERENCE
0.210330E-02	0.1722423E-05	0.16987997E-05	0.40662572E-07
0.19446E-02	0.1244154E-05	0.21217449E-05	-0.77692855E-07
0.17333E-02	0.22515544E-05	0.22909671E-05	-0.59312697E-07
0.16437E-02	0.24025213E-05	0.23985149E-05	0.94305372E-07
0.13105E-02	0.20876559E-05	0.23291097E-05	-0.28547220E-07
0.10780E-02	0.11123257E-05	0.31251429E-05	-0.22316271E-07
0.87232E-02	0.30859355E-05	0.32597036E-05	-0.38187586E-08

CONSTANTS ARE: INTERCEPT = 0.44975623E-04 SLOPE = -0.12731999E-01

THE STANDARD DEVIATION OBTAINED = 0.20882752E-07

GAS RATE (CC/MIN)	(D.F.-1)	(D.F.-1) (CALCULATED)	DIFFERENCE
250.0	0.8039	0.7695	0.0334
250.0	1.0330	1.0135	0.0245
500.0	1.2806	1.3571	-0.0765
500.0	1.4338	1.5755	-0.1717
800.0	2.0242	1.9939	0.0303
1000.0	2.6705	2.3935	0.2830
1400.0	3.8751	3.1524	0.7263

CONSTANTS ARE: INTERCEPT = 0.83029835E-02 SLOPE = 0.31854224E-01

THE STANDARD DEVIATION OBTAINED = 0.50103366E-01

TABLE - (C-2). (CONTD)

DIA. OF COLUMN = 2.5 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 67.60 MIN.

FEED RATE = 500 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 35.0 IN.

XB (G.MOLE/L)	RATE (G.MOLE/LIT-MIN)	RATE(CALCULATED) (G.MOLE/LIT-MIN)	DIFFERENCE
0.25574E-03	0.2448452E-05	0.24445393E-05	0.18611354E-06
0.21283E-03	0.2448452E-05	0.35492922E-05	-0.63750122E-07
0.19869E-03	0.34125743E-05	0.41697376E-05	-0.25723330E-06
0.19034E-03	0.43312366E-05	0.44179151E-05	-0.86678483E-07
0.18501E-03	0.4475571E-05	0.45420011E-05	-0.66193934E-07
0.18917E-03	0.51700332E-05	0.50383506E-05	0.71573595E-07
0.16744E-03	0.54625289E-05	0.52865335E-05	0.17597540E-06
0.14750E-03	0.51700333E-05	0.56587096E-05	-0.40239684E-07

CONSTANTS ARE: INTERCEPT = 0.1270194E-04 SLOPE = -0.29352866E-01

THE STANDARD DEVIATION OBTAINED = 0.49129170E-07

GAS RATE (CC/MIN)	(O.F-1)	(O.F-1) (CALCULATED)	DIFFERENCE
250.0	0.9436	0.9607	-0.0112
400.0	0.9029	0.8913	0.0016
600.0	0.9447	0.9695	-0.0251
825.0	1.0233	1.0374	-0.0159
1000.0	1.1377	1.1240	0.0067
1200.0	1.3438	1.3373	0.0065
1600.0	1.4671	1.5344	-0.0673
1800.0	1.6738	1.6589	0.0196

CONSTANTS ARE: INTERCEPT = 0.11530034E-01 SLOPE = 0.66234624E-00

THE STANDARD DEVIATION OBTAINED = 0.96981525E-02

TABLE - (C-2). (CONTD)

DIA. OF COLUMN = 0.5 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 30.45 MIN.

FEED RATE = 7500/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 35.00 IN.

X _B (G.MOLE/L)	RATE (G.MOLE/LIT-MIN)	RATE (CALCULATED) (G.MOLE/LIT-MIN)	DIFFERENCE
0.3042E-03	0.28457E-05	0.23231277E-05	0.32273238E-06
0.27971E-03	0.34317265E-05	0.35144576E-05	-0.10273106E-06
0.27055E-03	0.37652081E-05	0.39116148E-05	-0.14632678E-06
0.25365E-03	0.44743231E-05	0.47058975E-05	-0.23006942E-06
0.2224E-03	0.51155483E-05	0.57980269E-05	-0.17511411E-07
0.21984E-03	0.6240453E-05	0.62944582E-05	-0.36062374E-07
0.18671E-03	0.84265754E-05	0.78830435E-05	0.14353191E-06
0.1775E-03	0.83117311E-05	0.82831953E-05	0.31535819E-07

CONSTANTS ARE: INTERCEPT = 0.16520223E-04 SLOPE = -0.46971753E-01

THE STANDARD DEVIATION OBTAINED = 0.57589062E-07

GAS RATE (CC/MIN)	(D.F-1)	(D.F-1) (CALCULATED)	DIFFERENCE
300.0	0.3021	0.2990	0.0031
400.0	0.4205	0.3713	0.0491
600.0	0.4848	0.5039	-0.0391
800.0	0.5529	0.6258	-0.0633
1000.0	0.7202	0.7423	-0.0201
1200.0	0.9029	0.8493	0.0464
1600.0	1.1077	1.0547	0.0760
1800.0	1.2321	1.1525	0.0796

CONSTANTS ARE: INTERCEPT = 0.47762031E-02 SLOPE = 0.75303824E-01

THE STANDARD DEVIATION OBTAINED = 0.1881355E-01

TABLE - (C-2). (CONT'D)

DIA. OF COLUMN = 4.00 IN.
 DIA. OF DIFFUSER = 7.50 IN.
 RESIDENCE TIME = 57.66 MIN.

FEED RATE = 5000 CC/MIN.
 DIFFUSER = BRASS - D2
 LIQUID LEVEL = 14.00 IN.

Y ₁ (G.MOLE/L)	X ₁ (G.MOLE/LIT-4IN)	X ₂ (G.MOLE/LIT-4IN)	DIFFERENCE
0.22379E-02	1.3151237E-05	1.29111770E-05	0.10415170E-06
0.18172E-02	1.3021532E-05	1.4353354E-05	-0.13182216E-06
0.12302E-02	1.43310327E-05	1.53473183E-05	-0.15826117E-07
0.10901E-02	1.46106323E-05	1.57534264E-05	-0.14324360E-06
0.10146E-02	1.51417547E-05	1.59559703E-05	-0.92809387E-07
0.09831E-02	1.52353597E-05	1.62107965E-05	-0.75062417E-07
0.82434E-02	1.60327642E-05	1.54138503E-05	0.18913852E-07

CONSTANTS ARE: INTERCEPT = 0.3393020E-05 SLOPE = -0.24015900E-01

THE STANDARD DEVIATION OBTAINED = 0.36727039E-07

GAS RATE (CC/MIN)	(O.F-2)	(O.F-1) (CALCULATED)	DIFFERENCE
800.0	1.7361	1.7763	-0.0422
1000.0	1.1937	1.1883	0.0054
1500.0	2.1350	2.1253	0.0097
1800.0	2.6058	2.4493	0.1565
2000.0	1.9052	2.7346	-0.8294
2500.0	3.3675	3.4517	-0.0842
3000.0	4.2077	4.1752	0.0325

CONSTANTS ARE: INTERCEPT = 0.93763431E-03 SLOPE = 0.10437346E-01

THE STANDARD DEVIATION OBTAINED = 0.55302789E-01

TABLE - (C-2). (CONTD)

DIA. OF COLUMN = 0.00 IN.
 DIA. OF DIFFUSER = 0.50 IN.
 RESIDENCE TIME = 35.65 MIN.

FEED RATE = 75 CC/MIN.
 DIFFUSER = BRASS - D2
 LIQUID LEVEL = 14.00 IN.

X _F (GMOLF/L)	Y _F (G. MOLE/LIT-MIN)	RATE (CALCULATED) (G. MOLE/LIT-MIN)	DIFFERENCE
0.247 8E-03	0.3705326 E-05	0.35981243E-05	0.10620170E-06
0.22359E-03	0.47011988E-05	0.4819 168E-05	-0.50818016E-07
0.18178E-03	0.60707416E-05	0.63016614E-05	-0.22491986E-06
0.16487E-03	0.64859907E-05	0.69022235E-05	-0.83767191E-07
0.14798E-03	0.76813079E-05	0.75027683E-05	-0.21480446E-07
0.13700E-03	0.75709067E-05	0.70781413E-05	0.42825377E-07
0.12947E-03	0.80241177E-05	0.81593554E-05	-0.64462256E-07

CONSTANTS ARE: INTERCEPT = 0.12757729E-04 SLOPE = -0.35515506E-01

THE STANDARD DEVIATION OBTAINED = 0.39876802E-07

GAS RATE (CC/MIN)	(D.F-1)	(D.F-1) (CALCULATED)	DIFFERENCE
600.0	0.5269	0.5743	-0.0374
725.0	0.7730	0.8367	-0.0637
1000.0	1.1842	1.0503	0.1299
1200.0	1.4768	1.3020	0.1009
1400.0	1.7786	1.5633	0.1153
1600.0	1.9846	1.8305	0.0541
2000.0	2.0612	2.3529	-0.3217

CONSTANTS ARE: INTERCEPT = 0.29908540E-12 SLOPE = 0.11818457E-01

THE STANDARD DEVIATION OBTAINED = 0.55733815E-01

TABLE - (C-2). (CONT'D)

DIA. OF COLUMN = 4. IN.
 DIA. OF DIFFUSER = 2.50 IN.
 RESIDENCE TIME = 57.6 MIN.

FEED RATE = 500 CC/MIN.
 DIFFUSER = S. STEEL
 LIQUID LEVEL = 14.00 IN.

Y ₁ (G.MOLE/L)	X ₁ (G.MOLE/LIT-MIN)	X ₂ (CALCULATED) (G.MOLE/LIT-MIN)	DIFFERENCE
0.14024E-02	0.25216763E-05	0.35345214E-05	0.10708482E-06
0.13064E-02	0.43075370E-05	0.44367208E-05	-0.11904194E-06
0.13977E-02	0.49623322E-05	0.50376421E-05	-0.75509888E-07
0.12250E-02	0.55219107E-05	0.55324200E-05	-0.85183274E-08
0.11700E-02	0.6154535E-05	0.52535345E-05	0.96013089E-07

CONSTANTS: INTERCEPT = 0.20537156E-05 SLOPE = -0.28798319E-01

THE STANDARD DEVIATION OBTAINED = 0.40315839E-07

GAS RATE (CC/MIN)	(O.F-1)	(O.F-1) (CALCULATED)	DIFFERENCE
480.0	1.1333	1.1529	-0.0204
540.0	1.4571	1.4455	-0.0184
630.0	1.8355	1.8339	-0.00483
1000.0	2.2522	2.2552	-0.00322
1175.0	2.8765	2.5875	0.2889

CONSTANTS: INTERCEPT = 0.7557473E-02 SLOPE = 0.82569814E-01

THE STANDARD DEVIATION OBTAINED = 0.21936240E-01

TABLE - (C-2). (CONTD)

DIA. OF COLUMN = 4.00 IN.
 DIA. OF DIFFUSER = 2.00 IN.
 RESIDENCE TIME = 57.68 MIN.

FEED RATE = 5000 CC/MIN.
 DIFFUSER = BRASS - A
 LIQUID LEVEL = 14.00 IN.

X ₂ (GMOLE/L)	RATE (G. MOLE/LIT-MIN)	RATE (CALCULATED) (G. MOLE/LIT-MIN)	DIFFERENCE
0.20715E-03	0.34147524E-05	0.4031355E-05	0.11616976E-07
0.16910E-03	0.41052881E-05	0.41049725E-05	0.31559466E-09
0.15210E-03	0.44374993E-05	0.44165964E-05	0.13623312E-07
0.13105E-03	0.47568371E-05	0.48168059E-05	-0.25968802E-07
0.11837E-03	0.49072465E-05	0.50477516E-05	-0.54405064E-07
0.10665E-03	0.52731098E-05	0.52745973E-05	-0.25675035E-08
0.97232E-04	0.564321157E-05	0.54306611E-05	0.57444595E-07

CONSTANTS ARE : INTERCEPT = 0.72242410E-05 SLOPE = -0.18446397E-01

THE STANDARD DEVIATION OBTAINED = 0.12172951E-07

GAS RATE (CC/MIN)	(D.F-1)	(D.F-1) (CALCULATED)	DIFFERENCE
1600.0	0.9123	0.9220	-0.0087
2000.0	1.3432	1.3362	0.0070
2400.0	1.6742	1.6781	-0.0039
2700.0	2.0042	1.9438	0.0604
3075.0	2.3482	2.3012	0.0470
3450.0	2.7502	2.6546	0.0954
4000.0	3.8761	3.2172	0.6589

CONSTANTS ARE : INTERCEPT = 0.82758653E-04 SLOPE = 0.12741795E-01

THE STANDARD DEVIATION OBTAINED = 0.23816629E-01

TABLE - (C-2). (CONTD)

DIA. OF COLUMN = 1.5 IN.
 DIA. OF DIFFUSER = 2.5 IN.
 RESIDENCE TIME = 57.4 MIN.

FEED RATE = 5000/LIN.
 DIFFUSER = BRASS - 1
 LIQUID LEVEL = 14.00 IN.

X ₀ (G.MOLE/L)	RATE (G.MOLE/LIT-MIN)	RATE (CALCULATED) (G.MOLE/LIT-MIN)	DIFFERENCE
0.2304E-03	0.29257604E-05	0.29927596E-05	0.30067395E-08
0.21137E-03	0.33103941E-05	0.32886755E-05	0.21168942E-07
0.17538E-03	0.41267841E-05	0.41311091E-05	-0.54325028E-07
0.14796E-03	0.46831899E-05	0.47192635E-05	-0.29074727E-07
0.12687E-03	0.51430916E-05	0.51483926E-05	0.94559255E-07
0.11212E-03	0.56753193E-05	0.54574631E-05	0.18336323E-07
0.10267E-03	0.60195200E-05	0.56555418E-05	-0.53613813E-07

CONSTANTS AND : INTERCEPT = 0.77401658E-05 SLOPE = -0.20822294E-01

THE STANDARD DEVIATION OBTAINED = 0.18297765E-07

GAS RATE (CC/MIN)	(O.F-1)	(O.F-1) (CALCULATED)	DIFFERENCE
500.0	0.7252	0.7128	0.0073
1000.0	0.8750	0.8913	-0.0060
1500.0	1.2866	1.2946	-0.0080
2000.0	1.6736	1.7011	-0.0226
2500.0	2.1255	2.1025	0.0225
3000.0	2.5377	2.4996	0.0380
3500.0	2.8662	2.8937	-0.0277

CONSTANTS AND: INTERCEPT = 0.12528137E-02 SLOPE = 0.94926345E-01

THE STANDARD DEVIATION OBTAINED = 0.83150728E-02

TABLE - (C-2). (CONT'D)

DIA. OF COLUMN = 4. MM.
 DIA. OF DIFFUSER = 2.57 IN.
 RESIDENCE TIME = 37.68 MIN.

FEED RATE = 5000/MIN.
 DIFFUSER = BRASS - C
 LIQUID LEVEL = 14.7 IN.

X _F (G.MOLE/L)	RATE (G.MOLE/LIT-MIN)	RATE (CALCULATED) (G.MOLE/LIT-MIN)	DIFFERENCE
0.27715E-02	0.3477495E-05	0.34432646E-05	0.48485163E-07
0.16910E-02	0.4277154E-05	0.42412066E-05	-0.33491233E-07
0.16764E-02	0.4378350E-05	0.44187464E-05	-0.42396117E-07
0.14738E-02	0.46226401E-05	0.46850600E-05	-0.51461939E-07
0.13251E-02	0.48301612E-05	0.48626725E-05	0.17558705E-07
0.1226E-02	0.50771247E-05	0.52175874E-05	0.59337253E-07

CONSTANTS APP: INTERCEPT = 0.7732549E-05 SLOPE = -0.20998619E-01

THE STANDARD DEVIATION OBTAINED = 0.17936504E-07

GAS RATE (CC/MIN)	(O.F-1)	(O.F-1) (CALCULATED)	DIFFERENCE
600.0	0.4133	0.9942	-0.0809
825.0	1.1432	1.2430	0.1008
1000.0	1.4671	1.4225	0.0446
1250.0	1.6786	1.6165	0.0621
1500.0	1.8662	1.8903	-0.0243
2000.0	2.2328	2.3127	-0.0800

CONSTANTS APP: INTERCEPT = 0.11204779E-01 SLOPE = 0.70121312E-02

THE STANDARD DEVIATION OBTAINED = 0.29530503E-01

TABLE - (C-2). (CONTD)

DIA. OF COLUMN = 4.0 IN.
 DIA. OF DIFFUSER = 2.5 IN.
 RESTORAC TIME = 37.56 MIN.

FEED RATE = 500 CC/MIN.
 DIFFUSER = BRASS - D
 LIQUID LEVEL = 14.00 IN.

XW (G/MILE/L)	RATE (G. MOLE/LIT-MIN)	RATE (CALCULATED) (G. MOLE/LIT-MIN)	DIFFERENCE
0.27471E-05	0.22175420E-05	0.21216807E-05	0.96940612E-07
0.18812E-05	0.38722565E-05	0.40240748E-05	-0.15181831E-06
0.17121E-05	0.43683187E-05	0.45781920E-05	-0.93832568E-08
0.13538E-05	0.38373517E-05	0.51306906E-05	-0.42759393E-07
0.10931E-05	0.56134654E-05	0.56413674E-05	-0.43401997E-07
0.00841E-05	0.2116926E-05	0.6068256E-05	0.15044225E-06

CONSTANTS ARE: INTERCEPT = 0.79536539E-05 SLOPE = -0.20941421E-01

THE STANDARD DEVIATION OBTAINED = 0.47441734E-07

GAS RATE (CC/MIN)	(O.F-1)	(O.F-1) (CALCULATED)	DIFFERENCE
450.0	0.4205	0.5124	-0.0919
850.0	1.1057	0.8325	0.2742
1000.0	1.2148	1.4702	-0.1554
1080.0	1.0207	1.7834	0.1412
1571.0	2.6656	2.5110	0.0948
2000.0	5.3605	3.5710	-0.3105

CONSTANTS ARE: INTERCEPT = 0.16104310E-03 SLOPE = 0.13201466E-01

THE STANDARD DEVIATION OBTAINED = 0.80476280E-01

TABLE - (C-2). (CONT'D)

DIA. OF COLUMN = 7.5 IN.
 DIA. OF DIFFUSER = 2.5 IN.
 RESIDENCE TIME = 122.78 MIN.

FEED RATE = 5000 CC/MIN.
 DIFFUSER = BRASS - D2
 LIQUID LEVEL = 14.50 IN.

KE (G.MOLE/L)	RATE (G.MOLE/LIT-MIN)	RATE(CALCULATED) (G.MOLE/LIT-MIN)	DIFFERENCE
0.10041E-13	0.2261461E-05	0.22581671E-05	-0.16761075E-07
0.10057E-13	0.23263266E-05	0.23122811E-05	-0.14044417E-07
0.84250E-14	0.24346486E-05	0.24746250E-05	0.10023541E-07
0.76622E-14	0.25459021E-05	0.25422587E-05	-0.36334313E-08
0.62759E-04	0.25237370E-05	0.25055929E-05	-0.71559043E-08
0.53412E-04	0.25612344E-05	0.20555078E-05	-0.37734935E-05

CONSTANTS ARE: INTERCEPT = 0.31751545E-05 SLOPE = -0.85337870E-02

THE STANDARD DEVIATION OBTAINED = 0.42729695E-08

GAS RATE (CC/MIN)	(O.F-1)	(O.F-1) (CALCULATED)	DIFFERENCE
1600.0	2.4058	2.4053	0.1405
2000.0	3.9285	3.7591	-0.2325
2400.0	3.6375	3.7058	-0.1083
2700.0	4.1724	4.0891	-0.0833
3000.0	4.0612	4.5277	0.1541
3400.0	5.242	5.2555	-0.0156

CONSTANTS ARE: INTERCEPT = 0.19645812E-02 SLOPE = 0.96706706E-01

THE STANDARD DEVIATION OBTAINED = 0.56826282E-01

TABLE - (C-2). (CONTD)

DIA. OF COLUMN = 4.75 IN.
 DIA. OF DIFFUSER = 2.50 IN.
 RESIDENCE TIME = 46.62 MIN.

FEED RATE = 7500/MIN.
 DIFFUSER = BRASS - D2
 LIQUID LEVEL = 14.0 IN.

X	RATE	RATE (CALCULATED)	DIFFERENCE
(G.MOLE/L)	(G.MOLE/LIT-MIN)	(G.MOLE/LIT-MIN)	
0.2715E-02	0.2204237E-05	0.2198868E-05	0.2530945E-07
0.1691E-02	0.2071118E-05	0.2094939E-05	-0.2387059E-07
0.15210E-02	0.2091144E-05	0.2015499E-05	-0.2435444E-07
0.13510E-02	0.3314352E-05	0.3136217E-05	-0.2115757E-07
0.11837E-02	0.3323378E-05	0.3356522E-05	-0.2554406E-07
0.07230E-02	0.3031351E-05	0.2832167E-05	-0.9830913E-07
0.17491E-02	0.3572397E-05	0.3465777E-05	0.1056132E-06
0.1514E-02	0.3535295E-05	0.3577033E-05	0.6225582E-07

CONSTANTS ARE: INTERCEPT = 0.402111E-05 SLOPE = -0.1304034E-01

THE STANDARD DEVIATION OBTAINED = 0.2076762E-07

GAS RATE	(O.F-1)	(O.F-1)	DIFFERENCE
(CC/MIN)		(CALCULATED)	
1500.0	1.9133	1.9277	-0.0144
1500.0	1.2433	1.4533	-0.1195
1600.0	1.6042	1.5733	0.0308
1800.0	1.9227	1.7960	0.1336
2250.0	2.3482	2.3087	0.0402
2500.0	2.5761	2.5982	-0.0221
2700.0	2.6058	2.8337	-0.2277
3000.0	2.9052	3.1391	-0.2329

CONSTANTS ARE: INTERCEPT = 0.324111E-05 SLOPE = 0.1123964E-01

THE STANDARD DEVIATION OBTAINED = 0.7855200E-01

TABLE - (C-3).

CALCULATED RATE OF SEPARATION FROM THE CORRELATION

DIA. OF COLUMN = 2.00 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 28.84 MIN.

FEED RATE = 25 CC/MIN.
 DIFFUSER = BRASS - 01
 LIQUID LEVEL = 14.00 IN.

RATE (G. MOLE/LIT-MIN)	RATE (CALC) (G. MOLE/LIT-MIN)	DEVIATION
0.4927786E-05	0.61356131E-05	-0.12078272E-05
0.5543774E-05	0.69657041E-05	-0.13215176E-05
0.24327277E-05	0.82683310E-05	-0.36546771E-06
0.1751792E-04	0.85152952E-05	0.15554970E-05
0.11737524E-04	0.89199908E-05	0.28175336E-05
0.02543149E-04	0.93939261E-05	0.32542230E-05

PER CENT STANDARD DEVIATION OBTAINED = 0.20568924E 01

TABLE - (C-3). (CONTD)

DIA. OF COLUMN = 7.00 IN.

FEED RATE = 5000/MIN.

DIA. OF DIFFUSER = 1.25 IN.

DIFFUSER = BRASS - D1

RESIDENCE TIME = 14.40 MIN.

LIQUID LEVEL = 14.00 IN.

RATE (G. MOLE/LIT-MIN)	RATE (CALC) (G. MOLE/LIT-MIN)	DEVIATION
0.03151530E-05	0.1541E260E-04	-0.85941019E-05
0.03905303E-05	0.17129901E-04	-0.77394525E-05
0.12483959E-04	0.18849736E-04	-0.63677768E-05
0.18570440E-04	0.21820219E-04	-0.52497780E-05
0.17827011E-04	0.22671918E-04	-0.47040085E-05
0.18044800E-04	0.23383618E-04	-0.52988180E-05
0.23425302E-04	0.24790672E-04	-0.12953096E-05
0.22905847E-04	0.21382453E-04	0.15244441E-05

PER CENT STANDARD DEVIATION OBTAINED = 0.33413467E 01

TABLE - (C-3). (CONTD)

DIA. OF COLUMN = 2.0 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 9.61 MIN.

FEED RATE = 75 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.00 IN.

RATE (G. MOLE/LIT-MIN)	RATE (CALC) (G. MOLE/LIT-MIN)	DEVIATION
0.09017574E-05	0.25032300E-04	-0.17280530E-04
0.07087034E-05	0.24979090E-04	-0.16180988E-04
0.14034354E-04	0.27737115E-04	-0.13677751E-04
0.15061211E-04	0.29391429E-04	-0.13330719E-04
0.17741331E-04	0.23640324E-04	-0.11098993E-04
0.20204180E-04	0.30495139E-04	-0.10270989E-04
0.01002245E-04	0.30495139E-04	-0.88928937E-05
0.04365200E-04	0.31046750E-04	-0.66604598E-05

PER CENT STANDARD DEVIATION OBTAINED = 0.41666322E 01

TABLE - (C-3). (CONTD)

DIA. OF COLUMN = 2.50 IN.

FEED RATE = 25CC/MIN.

DIA. OF DIFFUSER = 1.25 IN.

DIFFUSER = BRASS - D1

RESIDENCE TIME = 45.76 MIN.

LIQUID LEVEL = 14.00 IN.

RATE (G. MOLE/LIT-MIN)	RATE (CALC) (G. MOLE/LIT-MIN)	DEVIATION
0.42828449E-05	0.43125583E-05	-0.48713446E-07
0.43756423E-05	0.44753369E-05	-0.40031136E-06
0.50913723E-05	0.51807202E-05	-0.81117014E-06
0.64853800E-05	0.53434878E-05	0.13218978E-05
0.71171178E-05	0.55505242E-05	0.15765836E-05
0.77592550E-05	0.57775615E-05	0.19823938E-05
0.81533823E-05	0.59403401E-05	0.22185422E-05
0.86235404E-05	0.60488601E-05	0.25396803E-05

PER CENT STANDARD DEVIATION OBTAINED = 0.23322783E-01

TABLE - (C-3). (CONTD)

DIA. OF COLUMN = 1.5 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 22.53 MIN.

FEED RATE = 50 CC/MIN.
 DIFFUSER = BRASS - 01
 LIQUID LEVEL = 14.00 IN.

RATE (G. MOLE/LIT-MIN)	RATE (CALC) (G. MOLE/LIT-MIN)	DEVIATION
0.52559499E-05	0.94478190E-05	-0.42408601E-05
0.59733413E-05	0.10163760E-04	-0.32399266E-05
0.10341092E-05	0.10969219E-04	-0.23808499E-05
0.74443701E-05	0.10476998E-04	-0.26126218E-05
0.86262405E-05	0.10969219E-04	-0.23439707E-05
0.82731487E-05	0.11237699E-04	-0.18595556E-05
0.76936719E-05	0.11282450E-04	-0.13887711E-05
0.11270470E-04	0.11953658E-04	-0.68318786E-06

PER CENT STANDARD DEVIATION OBTAINED = 0.22414989E 01

TABLE - (C-3). (CONT'D)

DIA. OF COLUMN = 2.50 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 15.02 MIN.

FEED RATE = 7500/MIN.
 DIFFUSER = BRASS - 01
 LIQUID LEVEL = 14.00 IN.

RATE (G. MOLE/LIT-MIN)	RATE (CALC) (G. MOLE/LIT-MIN)	DEVIATION
0.14688092E-05	0.14772511E-04	-0.91238162E-05
0.70213454E-05	0.15650624E-04	-0.86352775E-05
0.82758440E-05	0.16735527E-04	-0.77603827E-05
0.82109742E-04	0.16793347E-04	-0.66836046E-05
0.11006321E-04	0.17298560E-04	-0.56922290E-05
0.13977143E-04	0.18308987E-04	-0.43318441E-05
0.15627023E-04	0.18877356E-04	-0.32502576E-05
0.17808823E-04	0.19957923E-04	-0.20601001E-05

PER CENT STANDARD DEVIATION OBTAINED = 0.3219688E-01

TABLE - (C-3). (CONT'D)

DIA. OF COLUMN = 4.00 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 115.36 MIN.

FEED RATE = 2500/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.00 IN.

RATE (G. MOLE/LIT-MIN)	RATE (CALC) (G. MOLE/LIT-MIN)	DEVIATION
0.24447454E-05	0.17553538E-05	0.67939163E-06
0.24590263E-05	0.17653538E-05	0.69368252E-06
0.26023225E-05	0.18177170E-05	0.78460552E-06
0.27076553E-05	0.19114979E-05	0.88916750E-06
0.28324553E-05	0.19114979E-05	0.93096241E-06
0.29749239E-05	0.19114979E-05	0.95342602E-06

PER CENT STANDARD DEVIATION OBTAINED = 0.30167112E 01

TABLE - (C-3). (CONTD)

DIA. OF COLUMN = 4.00 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 87.6 MIN.

FEED RATE = 5000 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.0 IN.

RATE (G. MOLE/LIT-MIN)	RATE (CALC) (G. MOLE/LIT-MIN)	DEVIATION
0.39571188E-05	0.38296712E-05	-0.32265143E-06
0.36272325E-05	0.38573098E-05	-0.22935728E-06
0.29545336E-05	0.41336834E-05	-0.11700999E-05
0.42627021E-05	0.45216152E-05	-0.25684312E-06
0.27526516E-05	0.44929675E-05	-0.74041691E-06
0.34222423E-05	0.46587920E-05	-0.22654957E-06
0.34470652E-05	0.47069738E-05	0.69002635E-06

PER CENT STANDARD DEVIATION OBTAINED = 0.96479797E 00

TABLE - (C-3). (CONTD)

DIA. OF COLUMN = 4.00 IN.

FEED RATE = 7500 / MIN.

DIA. OF DIFFUSER = 1.25 IN.

DIFFUSER = BRASS - D1

RESIDENCE TIME = 80.45 MIN.

LIQUID LEVEL = 14.00 IN.

Q ₂ (G. MOLE/LIT-MIN)	RATE (CALC) (G. MOLE/LIT-MIN)	DEVIATION
0.37221914E-05	0.57321258E-05	-0.19389345E-05
0.47116682E-05	0.52684358E-05	-0.15367968E-05
0.50655618E-05	0.63559490E-05	-0.13593990E-05
0.55212411E-05	0.66534817E-05	-0.11355405E-05
0.58277745E-05	0.67559922E-05	-0.92858772E-06
0.65457239E-05	0.71460381E-05	-0.60330925E-06
0.70377255E-05	0.72923058E-05	-0.25458039E-06
0.75566189E-05	0.72923058E-05	-0.23568919E-06

PERCENT STANDARD DEVIATION OBTAINED = 0.96755496E-00

TABLE - (C-3). (CONT'D)

DIA. OF COLUMN = 6. IN.

FEED RATE = 5000/MIN.

DIA. OF DIFFUSER = 1.25 IN.

DIFFUSER = BRASS - D1

RESIDENCE TIME = 139.78 MIN.

LIQUID LEVEL = 14. IN.

RATE (G. MOLE/LIT-MIN)	RATE (CALC) (G. MOLE/LIT-MIN)	DEVIATION
0.17535211E-05	0.1510615E-05	0.25257155E-06
0.13714535E-05	0.15138832E-05	0.29380044E-06
0.19977345E-05	0.15321530E-05	0.35758057E-06
0.22652148E-05	0.16123877E-05	0.45453039E-06
0.19547214E-05	0.17160913E-05	0.14810212E-06
0.23965517E-05	0.17487855E-05	0.60986622E-06

PER CENT STANDARD DEVIATION OBTAINED = 0.90829223E-06

TABLE - (C-5). (CONT'D)

DIA. OF COLUMN = 0.00 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESISTANCE TIME = 46.92 MIN.

FEED RATE = 75 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.00 IN.

DATA (G. MOLE/LIT-MIN)	DATA (CALC) (G. MOLE/LIT-MIN)	DEVIATION
0.21481741E-05	0.23631983E-05	-0.21589823E-06
0.21964753E-05	0.24056617E-05	-0.22918560E-06
0.22424034E-05	0.24431242E-05	-0.10512576E-06
0.24274129E-05	0.25330492E-05	-0.35436642E-07
0.26423511E-05	0.26179750E-05	0.25383033E-07
0.27453648E-05	0.26604375E-05	0.74923264E-07
0.28722215E-05	0.27312080E-05	0.14708343E-06

PER CENT STANDARD DEVIATION OBTAINED = 0.20982575E 00

TABLE - (C-4).

FLOOD RATIO, FLOW VELOCITY, DRAINAGE TIME, F.DSQ, F.DSQ.DC**0.2

DIA. OF COLUMN = 2.00 IN.

FLOW RATE = 25CC/MIN.

DIA. OF DIFFUSER = 1.25 IN.

DIFFUSER = BRASS - D1

RESIDENCE TIME = 24.34 MIN.

LIQUID LEVEL = 14.00 IN.

GAS RATE (G/L/MIN)	X _R (G/L)	BUBBLE DIAMETER (CM)
150.0	0.111000	0.085442
200.0	0.096000	0.086429
250.0	0.074000	0.088255
300.0	0.071000	0.088635
350.0	0.063000	0.089347
400.0	0.055000	0.090248

F	TDR (SEC)	F.D (CM)
0.46143200E-02	0.10972269E-04	0.39687706E-03
0.29009871E-02	0.31842554E-03	0.35572945E-03
0.28190147E-01	0.64523491E-03	0.21357485E-02
0.34127577E-01	0.53226660E-03	0.30248864E-02
0.64493032E-01	0.45132983E-03	0.39758496E-02
0.46233235E-01	0.39397527E-03	0.42367947E-02

F.DSQ (CM/SEC)	F.DSQ.DC**0.2	VF (CM/SEC)
0.12909979E-04	0.46935359E-04	0.12387115E-00
0.73023956E-04	0.10236863E-03	0.16603327E-00
0.18844855E-03	0.25359163E-03	0.21056911E-00
0.26911077E-03	0.37179572E-03	0.25530434E-00
0.15922071E-03	0.49157941E-03	0.31105792E-00
0.35210000E-03	0.52914792E-03	0.34498137E-00

TABLE - (C-4). (CONTD)

DIA. OF COLUMN = 2.00 IN.

FEED RATE = 5000/MIN.

DIA. OF DIFFUSER = 1.25 IN.

DIFFUSER = BRASS - D1

RESIDENCE TIME = 14.42 MIN.

LIQUID LEVEL = 14.00 IN.

GAS RATE (CC/MIN)	X _B (G/L)	BUBBLE DIAMETER (CM)
150.0	0.11520	0.085115
200.0	0.10400	0.085851
250.0	0.09300	0.086655
300.0	0.07400	0.088255
325.0	0.06900	0.088733
350.0	0.06400	0.089241
400.0	0.05500	0.091248
500.0	0.07580	0.087999

F	TOR (SEC)	F.D (CM)
0.56225156E-02	0.10948474E 04	0.56367507E-03
0.12345675E-01	0.81640454E 03	0.10598924E-02
0.23437510E- 1	0.64578882E 03	0.20309882E-02
0.30545107E-01	0.53432026E 03	0.27010541E-02
0.35673307E-01	0.49055958E 03	0.31596238E-02
0.38725637E-01	0.45405564E 03	0.34559225E-02
0.59628070E-01	0.38450537E 03	0.62885731E-02
0.33450033E-01	0.30956138E 03	0.55843890E-02

F.DSD (CM/SEC)	F.DSQ.DC**0.2	VF (CM/SEC)
0.47077155E-04	0.66405992E-04	0.12411773E 00
0.90990126E-04	0.12594514E-03	0.16644931E 00
0.17509522E-03	0.24359937E-03	0.21042478E 00
0.24102312E-03	0.33351092E-03	0.25446588E 00
0.28025200E-03	0.38805304E-03	0.27700448E 00
0.30041050E-03	0.42687613E-03	0.29927975E 00
0.56755238E-03	0.78553124E-03	0.35341489E 00
0.40141090E-03	0.68018120E-03	0.43883407E 00

TABLE - (C-4). (CONT'D)

DIA. OF COLUMN = 0.5 IN.

DIA. OF DIFFUSER = 1.25 IN.

RESIDENCE TIME = 0.61 MIN.

FEED RATE = 7500/MIN.

DIFFUSER = BRASS - D1

LIQUID LEVEL = 14.00 IN.

GAS RATE (CC/MIN)	X ₀ (G/L)	BUBBLE DIAMETER (CM)
150.	0.11200	0.084362
200.	0.12300	0.084615
250.	0.11300	0.085244
300.	0.11700	0.085644
350.	0.11200	0.085509
400.	0.10300	0.085921
450.	0.11300	0.085921
500.	0.10100	0.086063

F	TOP (SEC)	F.D (CM)
0.4644240E-02	0.11972269E-04	0.39418112E-03
0.11772273E-01	0.81439381E-02	0.12504703E-02
0.24227442E-01	0.63732446E-02	0.30897408E-02
0.35741817E-01	0.53137695E-03	0.30611834E-02
0.44420443E-01	0.45126807E-03	0.38162165E-02
0.57150502E-01	0.38468042E-03	0.49112365E-02
0.40027894E-01	0.34937012E-03	0.42125396E-02
0.85712295E-01	0.31222266E-03	0.47948398E-02

F.DSQ (CM/SEC)	F.DSQ.DC**0.2	VF (CM/SEC)
0.13450522E-04	0.46299843E-04	0.12387115E-00
0.10840072E-03	0.14645165E-03	0.16686028E-00
0.26322303E-03	0.36446983E-03	0.21321940E-00
0.26315045E-03	0.36236553E-03	0.25573176E-00
0.32612320E-03	0.45166537E-03	0.30112910E-00
0.42107993E-03	0.53406964E-03	0.34872156E-00
0.36194711E-03	0.52097704E-03	0.38895698E-00
0.51285572E-03	0.57116910E-03	0.43523407E-00

TABLE - (C-4). (CONT'D)

DIA. OF COLUMN = 2.50 IN.

DIA. OF DIFFUSER = 1.25 IN.

RESIDENCE TIME = 45.86 MIN.

FIELD RATE = 2500/MIN.

DIFFUSER = BRASS - D1

LIQUID LEVEL = 14.00 IN.

GAS RATE (CC/MIN)	X3 (G/L)	BUBBLE DIAMETER (CM)
150.0	0.08640	0.087177
200.0	0.08160	0.087578
250.0	0.06780	0.089585
300.0	0.05500	0.090130
350.0	0.04360	0.090922
400.0	0.04320	0.091808
450.0	0.03840	0.092550
500.0	0.03520	0.093090

F	TOR (SEC)	F.D (CM)
0.17205592E-01	0.16923193E 04	0.15077784E-02
0.22155923E-01	0.12630337E 04	0.19355116E-02
0.20013288E-01	0.10116536E 04	0.18735069E-02
0.29065474E-01	0.83654199E 03	0.25656279E-02
0.29825927E-01	0.71603198E 03	0.27118407E-02
0.35610113E-01	0.62279272E 03	0.32692938E-02
0.40353225E-01	0.55252710E 03	0.35481972E-02
0.47043425E-01	0.49436523E 03	0.40120818E-02

F.D50 (CM/SEC)	F.D50).DC**0.2	VF (CM/SEC)
0.12144567E-03	0.19123671E-03	0.80298066E-01
0.1695743E-03	0.24532597E-03	0.10759014E 00
0.16733719E-03	0.24290867E-03	0.13432451E 00
0.23223317E-03	0.33455937E-03	0.16244251E 00
0.24656549E-03	0.35635254E-03	0.18978196E 00
0.27814714E-03	0.43439935E-03	0.21819454E 00
0.32838504E-03	0.47525741E-03	0.24616539E 00
0.37548125E-03	0.54064172E-03	0.27487767E 00

TABLE - (C-4). (CONTD)

DIA. OF COLUMN = 3.50 IN.

FEED RATE = 5000/MIN.

DIA. OF DIFFUSER = 1.25 IN.

DIFFUSER = BRASS - D1

RESIDENCE TIME = 22.53 MIN.

LIQUID LEVEL = 14.00 IN.

GAS RATE (CC/MIN)	X3 (G/L)	BUBBLE DIAMETER (CM)
150.0	0.10800	0.085576
200.0	0.10800	0.086135
250.0	0.09100	0.086810
270.0	0.08650	0.086391
300.0	0.09100	0.086810
350.0	0.08300	0.087048
370.0	0.08750	0.087088
400.0	0.08000	0.087716

F	TDR (SEC)	F.D. (CM)
0.73365087E-02	0.17094365E-04	0.67917720E-03
0.22084387E-01	0.12631567E-04	0.18953942E-02
0.21526410E-01	0.10110220E-04	0.18687120E-02
0.24022513E-01	0.91671294E-03	0.21444682E-02
0.26033176E-01	0.83841574E-03	0.22822544E-02
0.28317604E-01	0.71714473E-03	0.24649787E-02
0.33754156E-01	0.66559733E-03	0.29395770E-02
0.34383205E-01	0.62035449E-03	0.34546996E-02

F.DSQ (CMSQ)	F.DSQ.DC**0.2	VF (CM/SEC)
0.5912147E-04	0.84118466E-04	0.79540551E-01
0.18728702E-03	0.23628419E-03	0.11757965E-00
0.16222219E-03	0.23478360E-03	0.13440877E-00
0.18526486E-03	0.26812962E-03	0.14834940E-00
0.14612282E-03	0.28674072E-03	0.16207957E-00
0.21457235E-03	0.31154486E-03	0.18948746E-00
0.25500102E-03	0.3750699E-03	0.20410456E-00
0.30973118E-03	0.43857307E-03	0.21915214E-00

TABLE - (C-4). (CONTD)

DIA. OF COLUMN = 2.5 IN.

DIA. OF DIFFUSER = 1.25 IN.

RESIDENCE TIME = 15.52 MIN.

FEED RATE = 75 CC/MIN.

DIFFUSER = BRASS - D1

LIQUID LEVEL = 14.0 IN.

GAS RATE (CC/MIN)	X3 (G/L)	BUBBLE DIAMETER (CM)
150.0	0.12300	0.084799
200.0	0.11440	0.085154
250.0	0.11200	0.085310
300.0	0.10720	0.085631
350.0	0.10400	0.085851
400.0	0.09760	0.086310
450.0	0.09400	0.086579
500.0	0.08720	0.087112

F	TOR (SEC)	F.D (CM)
0.07212329E-02	0.17070318E-04	0.73972438E-03
0.13052563E-01	0.12735569E-04	0.11881110E-02
0.23066281E-01	0.10038096E-04	0.20189693E-02
0.40101225E-01	0.83255127E-03	0.28343939E-02
0.20543370E-01	0.70885962E-03	0.33548508E-02
0.40045651E-01	0.61386792E-03	0.42662770E-02
0.50013000E-01	0.54245197E-03	0.47634915E-02
0.00740147E-01	0.48421777E-03	0.54654181E-02

F.USQ (CMSQ)	F.DSQ.DC**1.2	VF (CM/SEC)
0.07212329E-02	0.90785530E-04	0.79603672E-01
0.13052563E-01	0.14642475E-03	0.10670114E-00
0.17023703E-03	0.24027733E-02	0.13470328E-00
0.24171037E-03	0.35127252E-03	0.16322112E-00
0.20545283E-03	0.42151509E-03	0.19170219E-00
0.40022269E-04	0.53202396E-03	0.22136676E-00
0.61261021E-03	0.59538906E-03	0.25051063E-00
0.47612351E-03	0.68905856E-03	0.28063817E-00

TABLE - (C-4). (CONTIN)

DIA. OF TUBING = 1/4 IN.

FEED RATE = 2500/MIN.

DIA. OF DIFFUSER = 1.25 IN.

DIFFUSER = BRASS - D1

DESIGN OF TIME = 115.36 MIN.

LIQUID LEVEL = 14. IN.

GAS RATE (CC/MIN)	XI (G/L)	BUBBLE DIAMETER (CM)
500.0	0.04500	0.091548
1000.0	0.04500	0.091548
1500.0	0.04500	0.092294
2000.0	0.03200	0.093675
2500.0	0.03200	0.093675
3000.0	0.03200	0.093675

F	TOR (SEC)	F.D (CM)
0.14077984E-02	0.11004963E-04	0.13711645E-03
0.17220285E-02	0.82518652E-03	0.15764841E-03
0.22047218E-02	0.65477051E-03	0.21178927E-03
0.25269812E-02	0.54968091E-03	0.23671130E-03
0.26982705E-02	0.41219751E-03	0.25107758E-03
0.26987414E-02	0.32931787E-03	0.23407045E-03

F.DSQ (CM/SEC)	F.DSQ.DC** .2	VF (CM/SEC)
0.12552745E-04	0.19958012E-04	0.12348162E-00
0.14432407E-04	0.22945551E-04	0.16467786E-00
0.18544863E-04	0.31778227E-04	0.20596546E-00
0.22174055E-04	0.35255158E-04	0.24721611E-00
0.23514705E-04	0.37394871E-04	0.32967198E-00
0.21425122E-04	0.34361834E-04	0.41201520E-00

TABLE - (C-4). (CONT'D)

DIA. OF COLUMN = 4.75 IN.

FEED RATE = 5000/MIN.

DIA. OF DIFFUSER = 1.25 IN.

DIFFUSER = BRASS - D1

RESIDENCE TIME = 47.63 MIN.

LIQUID LEVEL = 14.00 IN.

GAS RATE (G/MIN)	X5 (G/L)	BUBBLE DIAMETER (CM)
575.0	0.07525	0.088162
675.0	0.07420	0.088255
1000.0	0.06420	0.089241
1200.0	0.05300	0.090870
1400.0	0.05100	0.090742
2000.0	0.04500	0.091548
2500.0	0.04000	0.092294

F	TOR (SEC)	F.D (CM)
0.18222770E-02	0.11001304E-04	0.16133505E-03
0.28046118E-02	0.82429150E-03	0.24751993E-03
0.42013570E-02	0.65845679E-03	0.38209395E-03
0.52074813E-02	0.54810449E-03	0.48956135E-03
0.60761215E-02	0.41124912E-03	0.45145093E-03
0.60046181E-02	0.32838267E-03	0.45999442E-03
0.41163101E-02	0.21852202E-03	0.37991186E-03

F.DSD (CM/SEC)	F.DSD, DC**0.2	VF (CM/SEC)
0.14821519E-04	0.22614666E-04	0.12352169E-00
0.21844748E-04	0.34731696E-04	0.16485667E-00
0.34098528E-04	0.54214353E-04	0.20637643E-00
0.44886544E-04	0.70730588E-04	0.24792713E-00
0.60906417E-04	0.65132233E-04	0.33043236E-00
0.42111512E-04	0.66954613E-04	0.41336096E-00
0.35081611E-04	0.55748766E-04	0.61902666E-00

TABLE - (C-4). (CONT'D)

DIA. OF COLUMN = 4.0 IN.

FEED RATE = 7500/MIN.

DIA. OF DIFFUSER = 1.25 IN.

DIFFUSER = BRASS - D1

RESIDENCE TIME = 58.45 MIN.

LIQUID LEVEL = 14.0 IN.

GAS RATE (CC/MIN)	X ₀ (G/L)	BUBBLE DIAMETER (CM)
500.	0.09500	0.085429
1000.	0.08500	0.087292
1500.	0.08300	0.087459
2000.	0.07700	0.087981
2500.	0.07500	0.088162
3000.	0.06700	0.088922
3500.	0.06400	0.089241
4000.	0.05400	0.089241

F	TOP (SEC)	F.D (CM)
0.16833725E-02	0.11003135E-04	0.14380814E-03
0.40964671E-02	0.82325562E-03	0.35318825E-03
0.82724504E-02	0.65730170E-03	0.46108756E-03
0.39810045E-02	0.54703203E-03	0.51740079E-03
0.30377120E-02	0.41078380E-03	0.53670676E-03
0.72083835E-02	0.22823145E-03	0.64838201E-03
0.75463105E-02	0.25251367E-03	0.67522656E-03
0.64252105E-02	0.21001311E-03	0.57338458E-03

F.W.SU (CM/SEC)	F.O.SU, DC*W.2	VF (CM/SEC)
0.12624143E-04	0.19761501E-04	0.12357118E-03
0.0037437E-04	0.4913245E-04	0.16576213E-03
0.40720100E-04	0.64115855E-04	0.20650195E-03
0.45320030E-04	0.72333342E-04	0.24805039E-03
0.47010000E-04	0.75231306E-04	0.33080238E-03
0.57700000E-04	0.91749447E-04	0.41400629E-03
0.61000000E-04	0.95006201E-04	0.51764882E-03
0.71000000E-04	0.91056106E-04	0.62046504E-03

TABLE - (C-4). (CONTD)

PLATE COLUMN = 1.0 IN.
 DIA. OF DIFFUSER = 1.29 IN.
 RESIDENCE TIME = 124.78 MIN.

FEED RATE = 5000 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 14.00 IN.

FEED RATE (CC/MIN)	X ₂ (G/L)	BUBBLE DIAMETER (CM)
1000.0	0.05430	0.069241
1200.0	0.05322	0.089326
1400.0	0.06187	0.089585
1600.0	0.05280	0.090516
1800.0	0.04240	0.091927
4000.0	0.04320	0.092421

F	TR	F.D
(SEC)	(CM)	
0.02695949E-03	0.99154840E-03	0.20142597E-04
0.7496876E-03	0.82599072E-03	0.66943961E-04
0.1487787E-02	0.74284229E-03	0.13328232E-03
0.1617214E-02	0.57418481E-03	0.14820251E-03
0.1277117E-02	0.49513475E-03	0.15600933E-03
0.16124007E-02	0.67137475E-03	0.14901832E-03

F.DS	F.DS2.CC**0.2	VF
(G/S)		(CM/SEC)
0.26017201E-05	0.44842592E-05	0.13703996E-00
0.42705826E-05	0.10317609E-04	0.16451752E-00
0.11940731E-04	0.20537433E-04	0.18293244E-00
0.13674850E-04	0.23130051E-04	0.22869930E-00
0.14341438E-04	0.24728047E-04	0.27445032E-00
0.12771442E-04	0.23746465E-04	0.36591059E-00

TABLE - (C-4). (CONT'D)

DIST. COLUMN = 8.7 IN.
DIA. OF DIFFUSER = 1.25 IN.
RESIDENCE TIME = 86.52 MIN.
FEED RATE = 75 CC/MIN.
DIFFUSER = BRASS - D1
LIQUID LEVEL = 14.00 IN.

GAS RATE (CC/MIN)	K ₃ (G/L)	BUBBLE DIAMETER (CM)
1000 .	0.087760	0.087716
2000 .	0.07747	0.087927
3000 .	0.07527	0.088144
4000 .	0.07447	0.088596
5000 .	0.06557	0.089775
6000 .	0.06327	0.089326
7000 .	0.05927	0.089762

	TDR (SEC)	F.D (CM)
0.17774610E-03	0.82545338E-03	0.15591126E-04
0.79436815E-03	0.74335815E-03	0.59846428E-04
0.76741427E-03	0.59471264E-03	0.67642613E-04
0.84721311E-03	0.55759834E-03	0.76389129E-04
0.33256562E-03	0.49555811E-03	0.73277974E-04
0.7281175E-03	0.42471460E-03	0.33887193E-04
0.10828724E-03	0.37156753E-03	0.98181888E-04

F.O.S (CM/SEC)	F.O.S J.DC**0.2	VF (CM/SEC)
0.13675354E-05	0.23587415E-05	0.16442347E-00
0.11418234E-05	0.10589211E-04	0.18280548E-00
0.5972234E-05	0.1028243E-04	0.22850072E-00
0.4747704E-05	0.11569239E-04	0.24681418E-00
0.5527275E-05	0.11254492E-04	0.27421544E-00
0.7431272E-05	0.1222181E-04	0.31995595E-00
0.40137055E-05	0.15125714E-04	0.30572057E-00

TABLE - (C-4). (CONT'D)

DILUTE COLUMN = 7.00 IN.

FEED RATE = 2500/MIN.

DILUTE INFUSION = 1.25 IN.

DIFFUSER = BRASS - 01

RESIDENCE TIME = 115.36 MIN.

LIQUID LEVEL = 56.00 IN.

FEED RATE (CC/MIN)	XN (G/L)	BUBBLE DIAMETER (CM)
150.0	0.0428	0.086671
200.0	0.07347	0.087856
250.0	0.07287	0.088367
300.0	0.06640	0.088993
400.0	0.05580	0.090120

F	TDC (SEC)	F.D (CM)
0.00040597E-02	0.10030381E-04	0.071628738E-03
0.00020024E-01	0.01584058E-02	0.011445901E-02
0.00001045E-01	0.04571362E-02	0.000812114E-02
0.00000067E-01	0.03415820E-03	0.00027316127E-02
0.00000078E-01	0.000000004E-03	0.000000562775E-02

F.D.S	F.D.S.D.CC*0.2	VF (CM/SEC)
0.0000000000E-04	0.0000000000E-04	0.0000000000E-00
0.0000000000E-03	0.0000000000E-03	0.0000000000E-00
0.0000000000E-03	0.0000000000E-03	0.0000000000E-00
0.0000000000E-03	0.0000000000E-03	0.0000000000E-00
0.0000000000E-03	0.0000000000E-03	0.0000000000E-00

TABLE - (C-4). (CONTD.)

DIA. OF COLUMN = 2.00 IN.

FEED RATE = 5000/MIN.

DIA. OF DIFFUSER = 1.25 IN.

DIFFUSER = BRASS - D1

RESIDENCE TIME = 57.80 MIN.

LIQUID LEVEL = 55.00 IN.

GAS RATE (CC/MIN)	X _B (G/L)	BUBBLE DIAMETER (CM)
200.	0.00140	0.086357
300.	0.002720	0.087112
350.	0.005580	0.087242
400.	0.01430	0.087318
450.	0.06320	0.087442
500.	0.08120	0.087612
550.	0.07340	0.087355

F	T _{MR} (SEC)	F.D (CM)
0.17724310E-01	0.64956958E-03	0.15391351E-02
0.10000000E-01	0.54112852E-03	0.15878982E-02
0.10000000E-01	0.46440063E-03	0.14679693E-02
0.10000000E-01	0.40521194E-03	0.17098323E-02
0.10000000E-01	0.35075547E-03	0.18152857E-02
0.10000000E-01	0.22334761E-03	0.18003283E-02
0.10000000E-01	0.26047339E-03	0.19332611E-02

F.DS ₂ (CM/SEC)	F.DS ₂ .DC**0.2	VF (CM/SEC)
0.10000000E-03	0.18003550E-03	0.20920062E-00
0.10000000E-03	0.19145801E-03	0.25116974E-00
0.10000000E-03	0.17726282E-03	0.29261369E-00
0.10000000E-03	0.20662490E-03	0.33535612E-00
0.10000000E-03	0.21370400E-03	0.37772376E-00
0.10000000E-03	0.21331717E-03	0.41960329E-00
0.10000000E-03	0.23509020E-03	0.50427955E-00

TABLE - (C-4). (CONT'D)

DIA. OF COLUMN = 2.5 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 32.45 MIN.

FEED RATE = 7500/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 55.00 IN.

GAS RATE (CC/HRS)	X _B (G/L)	BUBBLE DIAMETER (CM)
200.	0.11343	0.084899
300.	0.11722	0.085031
500.	0.11247	0.085954
700.	0.09751	0.086310
900.	0.09361	0.086613
1000.	0.09122	0.086795

Q	T _{MR} (SEC)	F _{LD} (CM)
0.14722340E-01	0.81435374E-03	0.12587355E-02
0.24742353E-01	0.53142497E-03	0.29755840E-02
0.37191010E-01	0.45478125E-03	0.31971559E-02
0.42197916E-01	0.39578174E-03	0.35593592E-02
0.42133147E-01	0.34049585E-03	0.42165859E-02
0.52707161E-01	0.31321655E-03	0.45747124E-02

F _{LSQ} (CM/SEC)	F _{LSQ} .DC**0.2	VF (CM/SEC)
0.15605483E-03	0.14792238E-03	0.16636845E-00
0.15180111E-03	0.35137440E-03	0.25546857E-00
0.27463035E-03	0.38140965E-03	0.29881291E-00
0.31503242E-03	0.43715863E-03	0.34334564E-00
0.34525571E-03	0.50543720E-03	0.38861707E-00
0.40715163E-03	0.54957311E-03	0.43385235E-00

TABLE - (C-4). (CONT.)

DIA. OF COLUMN = 2.47 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 20.84 MIN.

FEED RATE = 2500/MIN.
 DIFFUSER = BRASS - 1/1
 LIQUID LEVEL = 3.95 IN.

GAS RATE (CC/MIN)	K ₁ (G/L)	BUBBLE DIAMETER (CM)
25 .	0.08450	0.037648
30 .	0.06722	0.038912
35 .	0.05587	0.0490130
40 .	0.04630	0.0501134
45 .	0.04322	0.0591878
47 .	0.04300	0.092204

F	FOR (SEC)	F.D (CM)
0.14218357E-01	0.15075451E-04	0.12413296E-02
0.27237352E-01	0.12563980E-04	0.24217309E-02
0.35322157E-01	0.99672337E-03	0.31887849E-02
0.33417746E-01	0.83228296E-03	0.30449464E-02
0.41463530E-01	0.70744250E-02	0.38056870E-02
0.46123100E-01	0.51610537E-02	0.42566098E-02

F.D50 (CM/SEC)	F.D50.DC**0.2	VF (CM/SEC)
0.14218357E-03	0.15538627E-03	0.80050826E-01
0.15322157E-03	0.31153140E-03	0.10815829E-00
0.28742180E-03	0.41548221E-03	0.13633943E-00
0.27710340E-03	0.42161430E-03	0.16327375E-00
0.45463530E-03	0.50537385E-03	0.19206616E-00
0.50215073E-03	0.56958126E-03	0.22054870E-00

TABLE - (C-4). (CONT'D)

DIA. OF COLUMN = 0.05 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESTORING TIME = 14.4 MIN.

FEED RATE = 50 CC/HR.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 3.96 IN.

GAS RATE (CC/HR)	K ₃ (G/L)	BUBBLE DIAMETER (CM)
15 .	0.1147	0.085415
20 .	0.1040	0.085551
25 .	0.0934	0.087177
30 .	0.0810	0.087716
35 .	0.0735	0.088242
40 .	0.0712	0.088519
45 .	0.0688	0.088753
50 .	0.0655	0.089775

	TOR (SEC)	F.O. (CM)
0.1586773E-01	0.16955523E-04	0.13120132E-02
0.2124263E-01	0.12512261E-04	0.26922734E-02
0.2741105E-01	0.93459751E-03	0.40974841E-02
0.3404313E-01	0.82171924E-03	0.40058626E-02
0.4064715E-01	0.70065325E-03	0.44712275E-02
0.4724838E-01	0.61347070E-03	0.45669324E-02
0.5384943E-01	0.53952202E-03	0.52836850E-02
0.6045041E-01	0.48505776E-03	0.52759796E-02

F.O.SQ (CM/SEC)	F.O.SQ.DC** .2	VF (CM/SEC)
0.1300827E-03	0.15219274E-03	0.89140233E-01
0.2302754E-03	0.33326773E-03	0.10860544E-00
0.2972363E-03	0.51528042E-03	0.13800174E-00
0.3574034E-03	0.53357125E-03	0.16537273E-00
0.4067738E-03	0.57134987E-03	0.19394320E-00
0.4547035E-03	0.58508595E-03	0.22187173E-00
0.4954739E-03	0.67046222E-03	0.25173104E-00
0.5400872E-03	0.68716327E-03	0.27954132E-00

TABLE - (C-4). (CONT'D)

DIA. OF COLUMN = 7.96 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 9.61 MIN.

FEED RATE = 75 CC/MIN.
 DIFFUSER = GRASS - D1
 LIQUID LEVEL = 8.96 IN.

GAS RATE (CC/MIN)	X _B (G/L)	BUBBLE DIAMETER (CM)
150.	0.11200	0.084862
200.	0.11100	0.085376
250.	0.11247	0.085964
300.	0.11380	0.085732
350.	0.09560	0.086429
400.	0.09200	0.086732
450.	0.08250	0.086920
500.	0.08300	0.087748

	T ₀₂ (SEC)	F.D (CM)
0.14184187E-01	0.16969339E-04	0.12276339E-02
0.31347477E-01	0.12643940E-04	0.17969422E-02
0.28771969E-01	0.19639430E-04	0.24389257E-02
0.10726770E-01	0.83459570E-03	0.26357304E-02
0.32541450E-01	0.71335410E-03	0.28211586E-02
0.47571960E-01	0.61536841E-03	0.41261800E-02
0.70754700E-01	0.55966470E-03	0.52943833E-02
0.74727400E-01	0.48656791E-03	0.50463527E-02

F.D ₀ (CM/SEC)	F.D ₀), DC**0.2	VF (CM/SEC)
0.13512750E-02	0.15230505E-03	0.50777112E-01
0.15841812E-02	0.22203579E-03	0.10747439E-00
0.20365912E-02	0.30343700E-03	0.13535559E-00
0.25048719E-02	0.32722737E-03	0.16262129E-00
0.24387471E-02	0.35254046E-03	0.19033432E-00
0.31573757E-02	0.51734620E-03	0.22093546E-00
0.45849340E-02	0.65470277E-03	0.2518471E-00
0.48327271E-02	0.63575389E-03	0.27921778E-00

TABLE - (C-4). (CONTD)

DIA. OF COLUMN = 1.5 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 115.3 MIN.

FEED RATE = 2500/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 35.0 IN.

GAS RATE (CY./MIN.)	K _G (G/L)	BUBBLE DIAMETER (CM)
250.0	0.03320	0.087442
350.0	0.03760	0.088292
500.0	0.05550	0.089075
500.0	0.05524	0.089411
750.0	0.04960	0.090922
1000.0	0.04380	0.092170
1500.0	0.03530	0.092815

F	TOR (SEC)	F.D (CM)
0.17020314E-01	0.10220273E-04	0.95159507E-03
0.31614144E-02	0.73272124E-03	0.72058616E-03
0.08421648E-02	0.51164639E-03	0.87668980E-03
0.27486700E-01	0.42459537E-03	0.12594105E-02
0.15190039E-01	0.31300903E-03	0.13756594E-02
0.15040244E-01	0.25421770E-03	0.14622316E-02
0.13276166E-01	0.18195082E-03	0.12879169E-02

F.D.S (CM/SEC)	F.D.S 2, DC**0.2	VF (CM/SEC)
0.03191040E-04	0.12040256E-03	0.13296211E-02
0.07021901E-04	0.92079121E-04	0.18563664E-02
0.25040000E-04	0.11302021E-03	0.26564544E-02
0.11180000E-03	0.16180729E-03	0.32011360E-02
0.13007700E-03	0.18102382E-03	0.42731476E-02
0.14171300E-03	0.19515151E-03	0.53454179E-02
0.14500000E-03	0.17390537E-03	0.74685007E-02

TABLE - (C-4). (CONTD)

DIA. OF COLUMN = 2.50 IN.
 DIA. OF DIFFUSER = 1.25 IN.
 RESIDENCE TIME = 57.6 MIN.

FEED RATE = 5000 CC/MIN.
 DIFFUSER = BRASS - D1
 LIQUID LEVEL = 36.00 IN.

GAS RATE (CC/MIN)	X _B (G/L)	BUBBLE DIAMETER (CM)
850.0	0.05530	0.086359
850.0	0.05320	0.087442
850.0	0.07520	0.088144
1250.0	0.07200	0.088443
1050.0	0.07540	0.088596
1350.0	0.06400	0.089241
1550.0	0.06550	0.089585
1400.0	0.05650	0.090130

F	TDR (SEC)	F.D (CM)
0.7795488E-02	0.75209077E-04	0.67332434E-03
0.9230665E-02	0.42655225E-03	0.80714771E-03
0.8747901E-02	0.32006982E-03	0.77106617E-03
0.12270754E-01	0.27583081E-03	0.10860530E-02
0.12706466E-01	0.25503345E-03	0.11257418E-02
0.18329113E-01	0.19559317E-03	0.13571497E-02
0.15714020E-01	0.15899135E-03	0.13630213E-02
0.14800103E-01	0.1413723E-03	0.13416850E-02

F.D.SQ (CMSQ)	F.D.SQ.DC**1.2	VF (CM/SEC)
0.6075411E-04	0.84166182E-04	0.18556833E-00
0.7037857E-04	0.16214749E-03	0.31897753E-00
0.7564651E-04	0.93364675E-04	0.42456329E-00
0.0853720E-04	0.13071660E-03	0.49265605E-00
0.09776170E-04	0.14434692E-03	0.53283203E-00
0.10748015E-03	0.17438104E-03	0.69438577E-00
0.12710445E-03	0.17672130E-03	0.85470325E-00
0.12097542E-03	0.17511414E-03	0.96122026E-00

TABLE - (C-+). (CONT'D)

DIA. OF COLUMN = 2.5 IN.

FEED RATE = 75CC/MIN.

DIA. OF DIFFUSER = 1.25 IN.

DIFFUSER = BRASS - D1

RESIDENCE TIME = 32.45 MIN.

LIQUID LEVEL = 35.0 IN.

GRS RATE (CC/MIN)	X3 (G/L)	BUBBLE DIAMETER (CM)
300.0	0.11527	0.085102
400.0	0.10567	0.085740
500.0	0.10240	0.085964
600.0	0.09600	0.086429
700.0	0.09727	0.087112
800.0	0.08520	0.087442
900.0	0.07840	0.088506
1000.0	0.06727	0.088912

T	TOR (SEC)	F.D (CM)
0.79699124E-02	0.85419743E-03	0.67820447E-03
0.92338486E-02	0.63982251E-03	0.79214107E-03
0.97599027E-02	0.42677759E-03	0.74847392E-03
0.11754004E-01	0.31942765E-03	0.02980033E-03
0.18403040E-01	0.25655145E-03	0.16650453E-02
0.17823001E-01	0.21147485E-03	0.15672138E-02
0.24170110E-01	0.15754408E-03	0.21418999E-02
0.23135700E-01	0.14019706E-03	0.21560750E-02

T. 0.52 (C 15.7)	F. 252.DC**3.2	VF (CM/SEC)
0.27718582E-04	0.89532451E-04	0.15928629E-03
0.27911172E-04	0.98297412E-04	0.21238697E-03
0.64141673E-04	0.93127315E-04	0.31840920E-03
0.30287470E-04	0.11630607E-03	0.42542619E-03
0.13499810E-03	0.20255950E-03	0.53594637E-03
0.11706325E-03	0.13083665E-03	0.64279503E-03
0.29076307E-03	0.27454217E-03	0.86255211E-03
0.14987485E-03	0.26457850E-03	0.96932673E-03

TABLE - (C-+). (CONT.)

DIA. OF COLUMN = 4.70 IN.
 DIA. OF DIFFUSER = 1.50 IN.
 RESIDENCE TIME = 57.68 MIN.

FEED RATE = 5000 CC/MIN.
 DIFFUSER = BRASS - D2
 LIQUID LEVEL = 14.00 IN.

GAS RATE (CC/MIN)	X ₁ (G/L)	BUBBLE DIAMETER (CM)
800.0	0.03540	0.087177
900.0	0.06840	0.088792
1500.0	0.04810	0.091134
1800.0	0.04160	0.092047
2000.0	0.03840	0.092550
2500.0	0.03440	0.093232
3000.0	0.03120	0.093830
F	TDK (SEC)	F.D (CM)
0.21450474E-02	0.1049783E-04	0.18752856E-03
0.42870082E-02	0.73236277E-03	0.29038999E-03
0.00000371E-02	0.43649390E-03	0.40231653E-03
0.00000100E-02	0.36388501E-03	0.87625114E-03
0.13150517E-01	0.32629272E-03	0.12179113E-02
0.10415005E-01	0.26123036E-03	0.11575613E-02
0.11483949E-01	0.21790463E-03	0.10747183E-02
F.D.SQ (G/GS)	F.D.SQ.DC**0.2	VF (CM/SEC)
0.16300502E-04	0.25923189E-04	0.12356073E-00
0.23757705E-04	0.40453004E-04	0.18554930E-00
0.92831738E-04	0.13074200E-03	0.31132150E-00
0.38616200E-04	0.12523800E-03	0.37344205E-00
0.11771751E-03	0.17921821E-03	0.41646624E-00
0.10002001E-03	0.17153853E-03	0.52519066E-00
0.10000000E-03	0.16032922E-03	0.52362134E-00

TABLE - (C-4). (CONT.)

DIAM. OF COLUMN = 4.75 IN.
 DIA. OF DIFFUSER = 2.50 IN.
 RESIDENCE TIME = 83.45 MIN.

FEED RATE = 75 CC/MIN.
 DIFFUSER = BRASS - D2
 LIQUID LEVEL = 14.00 IN.

GAS RATE (CC/MIN)	X ₂ (G/L)	BUBBLE DIAMETER (CM)
500.0	0.09750	0.086310
750.0	0.09450	0.087325
1000.0	0.08880	0.088753
1250.0	0.08240	0.089411
1500.0	0.05500	0.090130
1750.0	0.05200	0.090615
2000.0	0.04000	0.091001

F	TOR (SEC)	F.D (CM)
0.13412026E-02	0.11006321E-04	0.16707701E-03
0.42725754E-02	0.79313672E-03	0.37310272E-03
0.74442310E-02	0.65511133E-03	0.69477502E-03
0.13135323E-01	0.54341577E-03	0.12424402E-02
0.14185805E-01	0.45571875E-03	0.12650506E-02
0.15254817E-01	0.42695923E-03	0.13913354E-02
0.16122687E-01	0.32597461E-03	0.12851781E-02

F.DSD (CM/SEC)	F.DSD.00**F.2	VF (CM/SEC)
0.24688177E-04	0.23051005E-04	0.12353611E-00
0.32781214E-04	0.51851922E-04	0.17025900E-00
0.31553728E-04	0.93147035E-04	0.20711416E-00
0.14118773E-03	0.17652198E-03	0.25006628E-00
0.11481313E-03	0.18128132E-03	0.29178542E-00
0.12607621E-03	0.20845265E-03	0.33331541E-00
0.11695247E-03	0.13594645E-03	0.41687286E-00

TABLE - (C-4). (CONTD.)

DIA. OF COLUMN = 4.0 IN.
 DIA. OF DIFFUSER = 2.0 IN.
 RESIDENCE TIME = 57.63 MIN.

FEED RATE = 5000 CC/MIN.
 DIFFUSER = S. STEEL
 LIQUID LEVEL = 14.0 IN.

GAS RATE (CC/MIN)	X _T (G/L)	BUBBLE DIAMETER (CM)
400.	0.07200	0.067494
500.	0.06887	0.068350
600.	0.05290	0.069667
1000.	0.04540	0.069715
1100.	0.04387	0.070338

F	TOR (SEC)	F.D (CM)
0.04311674E-02	0.16458152E-04	0.30236319E-03
0.00885419E-02	0.11945533E-04	0.47073886E-03
0.12773677E-01	0.81586153E-03	0.89812418E-03
0.27000780E-01	0.64939771E-03	0.12535222E-02
0.25413108E-01	0.54262158E-03	0.16468454E-02

D.SQ (CM/SQ)	F.DSQ.DC**0.2	VF (CM/SEC)
0.00007766E-04	0.32446953E-04	0.82566977E-01
0.00002449E-04	0.51157315E-04	0.12415051E-00
0.00000652E-04	0.98524587E-04	0.16656011E-00
0.00000711E-04	0.13394227E-03	0.20925540E-00
0.00000590E-03	0.18417234E-03	0.24724231E-00

TABLE - (C-4). (CONT'D)

DIA. OF COLUMN = 4.0 IN.
 DIA. OF DIFFUSER = 2.5 IN.
 RESIDENCE TIME = 57.6 MIN.

FEED RATE = 500 CC/MIN.
 DIFFUSER = BRASS - A
 LIQUID LEVEL = 14.00 IN.

GAS RATE (CC/MIN)	X ₂ (G/L)	BUBBLE DIAMETER (CM)
1000 .0	0.07343	0.139463
2000 .0	0.06420	0.141652
3000 .0	0.05760	0.142777
4000 .0	0.0475	0.144331
5000 .0	0.04485	0.145369
6000 .0	0.04003	0.146503
7000 .0	0.03667	0.147335
	TOR (SEC)	F.H (CM)
0.02517129E-02	0.44233666E-03	0.17457431E-03
0.14111105E-02	0.23017576E-02	0.20015788E-03
0.16601522E-02	0.27516669E-03	0.22274056E-03
0.16772037E-02	0.24455923E-03	0.21350592E-03
0.13290711E-02	0.21476613E-03	0.19262369E-03
0.18420740E-02	0.19132449E-03	0.27000974E-03
0.02443885E-02	0.16495787E-03	0.33375375E-03
R. ASD (CM/SEC)	F. DSJ. DC**0.2	VF (CM/SEC)
0.04346501E-04	0.38709433E-04	0.30862552E-00
0.00255105E-04	0.45034264E-04	0.41156715E-00
0.01002143E-04	0.50553273E-04	0.49395341E-00
0.0015310E-04	0.48974251E-04	0.55505202E-00
0.20001941E-04	0.44627362E-04	0.63272882E-00
0.0005538E-04	0.6289540E-04	0.71025920E-00
0.40702240E-04	0.77430960E-04	0.82382095E-00

TABLE - (C-4). (CONT'D)

DIA. OF COLUMN = 4.0 IN.
 DIA. OF DIFFUSER = 2.5 IN.
 RESIDENCE TIME = 57.63 MIN.

FEED RATE = 5000 CC/MIN.
 DIFFUSER = BRASS - B
 LIQUID LEVEL = 14.0 IN.

GAS RATE (CC/MIN)	K ₃ (G/L)	BUBBLE DIAMETER (CM)
300 .	0.00723	0.103253
1000 .	0.00800	0.103998
1500 .	0.00500	0.105610
2100 .	0.00600	0.106361
2500 .	0.00400	0.108051
3000 .	0.00400	0.108991
3500 .	0.00380	0.109653

F	TDR (SEC)	F.D (CM)
0.100000000E+02	0.82507340E+03	0.19200047E+03
0.17722923E+03	0.55945484E+03	0.28831395E+03
0.28669850E+03	0.43958691E+03	0.30468234E+03
0.36717117E+03	0.32344165E+03	0.33862228E+03
0.51733333E+03	0.25314573E+03	0.55895979E+03
0.66751111E+03	0.21939425E+03	0.50986046E+03
0.40747111E+03	0.18415957E+03	0.44630992E+03

F.DS (CM/SEC)	F.DSV.DC**1.2	VF (CM/SEC)
0.19830943E+04	0.31529353E+04	0.16470045E+00
0.22000112E+04	0.47672787E+04	0.20606411E+00
0.42177002E+04	0.51160212E+04	0.30913109E+00
0.41223587E+04	0.66027322E+04	0.41248572E+00
0.60405842E+04	0.95126103E+04	0.51640344E+00
0.55171105E+04	0.88352783E+04	0.51937582E+00
0.48004516E+04	0.77897334E+04	0.72215767E+00

TABLE - (C-4). (CONT'D)

DIA. OF COLUMN = 4.0 IN.
 DIA. OF DIFFUSER = 2.5 IN.
 RESIDENCE TIME = 87.63 MIN.

FEED RATE = 5000 CC/MIN.
 DIFFUSER = BRASS - C
 LIQUID LEVEL = 14.00 IN.

GAS RATE (CC/MIN)	X _B (G/G)	BUBBLE DIAMETER (CM)
4000.0	0.07540	0.084473
4250.0	0.06400	0.085805
4500.0	0.06430	0.086136
4750.0	0.05500	0.085560
5000.0	0.05280	0.087031
5250.0	0.04540	0.087335

F	T _{OK} (SEC)	F.D (CM)
0.43741038E-02	0.10957729E-04	0.41190139E-03
0.40203555E-02	0.73713539E-03	0.47372002E-03
0.52020914E-02	0.65753423E-03	0.44984953E-03
0.52467023E-02	0.54315430E-03	0.45901816E-03
0.52053913E-02	0.43827235E-03	0.51046978E-03
0.62117000E-02	0.32359033E-03	0.54555829E-03

F, 150 (CM/SEC)	F.DS1.DC**0.2	VF (CM/SEC)
0.14704715E-04	0.55321274E-04	0.12389982E-00
0.42047734E-04	0.64627136E-04	0.17047274E-00
0.30763125E-04	0.61676741E-04	0.20657170E-00
0.39773344E-04	0.63244879E-04	0.24793454E-00
0.04426604E-04	0.70635288E-04	0.31005782E-00
0.47710000E-04	0.75138066E-04	0.41355437E-00

TABLE - (C-4). (CONTD)

DIA. OF TUBES = 4.7 IN.
 DIA. OF DIFFUSER = 2.5 IN.
 RESIDENCE TIME = 57.56 MIN.

FEED RATE = 5000 CC/MIN.
 DIFFUSER = BRASS - D
 LIQUID LEVEL = 14.00 IN.

GAS RATE (CC/MIN)	XX (G/L)	TUBE DIAMETER (CM)
4000.	0.15560	0.065432
5000.	0.07120	0.067553
10000.	0.05450	0.068040
13000.	0.05120	0.069220
16000.	0.04150	0.070245
20000.	0.03440	0.071149

T	TOR (SEC)	F.D (CM)
0.42040000E-03	0.14533511E-04	0.27510087E-03
0.5111470E-02	0.17110977E-04	0.41624508E-03
0.7733700E-02	0.65513185E-03	0.53062313E-03
0.10330000E-01	0.55423977E-03	0.70833334E-03
0.21020570E-01	0.43537842E-03	0.79359743E-03
0.14020700E-01	0.3250695E-03	0.10193400E-02

F.D50 (CM/SEC)	F.D50.DC** .2	VF (CM/SEC)
0.18070000E-04	0.23620052E-04	0.92862189E-01
0.22114413E-04	0.44705379E-04	0.13439846E-00
0.36205504E-04	0.57402227E-04	0.20710802E-00
0.4072114E-04	0.78021345E-04	0.24081763E-00
0.50740000E-04	0.88632674E-04	0.31176120E-00
0.70525400E-04	0.11551051E-03	0.41695935E-00

TABLE - (C-4). (CONT.)

DISCH. COLUMN = 8. IN.
 DIA. OF DIFFUSER = 2.6 IN.
 RESIDENCE TIME = 279.73 MIN.

FEED RATE = 50 CC/MIN.
 DIFFUSER = BPASS - D2
 LIQUID LEVEL = 14.00 IN.

GAS RATE (CC/MIN)	X ₁ (G/L)	BUBBLE DIAMETER (CM)
2670.	0.0415	0.092047
2680.	0.0420	0.092421
2690.	0.0425	0.093675
2700.	0.0430	0.094272
2710.	0.0435	0.094834
2720.	0.0440	0.095398

F	TDR (SEC)	F.D (CM)
0.12739754E-02	0.92875224E-03	0.11721044E-03
0.12851262E-02	0.74230859E-03	0.120379956E-03
0.12962770E-02	0.59365525E-03	0.123658702E-03
0.13074278E-02	0.54955139E-03	0.124342939E-03
0.13185786E-02	0.49477710E-03	0.122737186E-03
0.13297294E-02	0.42404419E-03	0.124007018E-03

F.D. (CM/SEC)	F.D.S.D. (CM/SEC)*0.2	VF (CM/SEC)
0.1701965E-04	0.13612557E-04	0.14631450E-00
0.1835818E-04	0.32476542E-04	0.18306398E-00
0.2142363E-04	0.38213169E-04	0.22898347E-00
0.22941379E-04	0.39558753E-04	0.24722981E-00
0.21587625E-04	0.37179790E-04	0.27464379E-00
0.21012241E-04	0.39458822E-04	0.32046175E-00

TABLE - (C-4). (CONT'D)

DIA. OF COLUMN = 8.0 IN.
 DIA. OF DIFFUSER = 8.5 IN.
 RESIDENCE TIME = 66.52 MIN.

FEED RATE = 7500/LIN.
 DIFFUSER = FRASS - D2
 LIQUID LEVEL = 14.0 IN.

GAS RATE (CC/MIN)	K ₁ (G/L)	BUBBLE DIAMETER (CM)
1000	0.074	0.087856
1500	0.064	0.089241
2000	0.057	0.089944
2500	0.0512	0.090716
3000	0.0448	0.091577
3500	0.0353	0.092815
4000	0.0415	0.092747
4500	0.0364	0.092550

F	T _{MR} (SEC)	F.D (CM)
0.11705305E-02	0.14311452E-04	0.10354782E-03
0.12455910E-02	0.99179614E-03	0.10221267E-03
0.13457111E-02	0.92821944E-03	0.16675852E-03
0.15147130E-02	0.82445216E-03	0.23575191E-03
0.16741101E-02	0.65448624E-03	0.26338757E-03
0.175417812E-02	0.54393709E-03	0.19143614E-03
0.1741104E-02	0.54792798E-03	0.52596430E-03
0.19124147E-02	0.43352354E-03	0.45464204E-03

F.D.00 (CM/SEC)	F.DS2.DC**0.2	VF (CM/SEC)
0.10872043E-03	0.15095488E-04	0.91437876E-01
0.11219316E-03	0.13727768E-04	0.13715231E-00
0.10928617E-04	0.25757715E-04	0.14639854E-00
0.11316913E-04	0.36875420E-04	0.16482258E-00
0.14129120E-04	0.41553805E-04	0.20608550E-00
0.17675320E-04	0.37476454E-04	0.22879481E-00
0.14315378E-04	0.83113391E-04	0.24809611E-00
0.14077139E-04	0.72550074E-04	0.27534306E-00

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